Les preuves du changement climatique, les tendances mondiales et régionales, le régime d'incendie, l'interaction avec les facteurs météorologiques et climatiques, changements récents

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cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

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1. Les preuves du changement climatique,
2. Les tendances mondiales et régionales,
3. Le régime d’incendie,
4. L'interaction avec les facteurs météorologiques et climatiques,
5. Changements récents

1. Les preuves du changement climatique

Centro Euro-Mediterraneo sui Cambiamenti Climatici

Climate Change, IPCC

Le Groupe d'experts intergouvernemental sur l'évolution du climat (IPCC en anglais) est l'organisme international chef de file pour l'évaluation des changements climatiques. Il a été créé en **1988** par le Programme des Nations Unies pour l'environnement (PNUE/UNEP) et l'Organisation météorologique mondiale (OMM/WMO) avec pour mission de présenter au monde l'état actuel des connaissances scientifiques sur les changements climatiques et leur incidence potentielle sur l'environnement et la sphère socio-économique.

En 2014 le IPCC a parachevé le cinquième Rapport d'évaluation, qui se divisé en trois parties (éléments scientifiques, conséquences, adaptation et vulnérabilité, et atténuation du changement climatique) dont sont responsables ses trois Groupes de travail, ainsi qu'un rapport de synthèse.

http://www.ipcc.ch/home_languages_main_french.shtml

Climate Change, IPCC

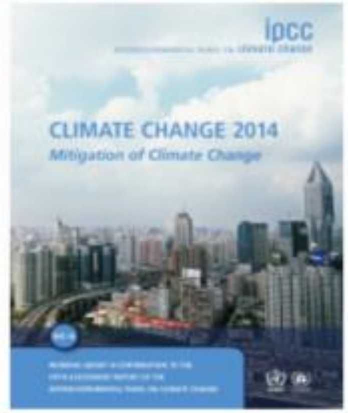
CHANGEMENTS CLIMATIQUES 2013
Les éléments scientifiques

Contribution du Groupe de travail I
au cinquième Rapport
d'évaluation du GIEC

Résumé à l'intention des décideurs, Résumé technique et Foire aux questions

Conclusions titres

Rapport



CHANGEMENTS CLIMATIQUES 2014
L'atténuation du changement climatique

Contribution du Groupe de travail III
au cinquième Rapport
d'évaluation du GIEC

Résumé à l'intention des décideurs
(disponible en anglais seulement)

Rapport (version définitive)

CHANGEMENTS CLIMATIQUES 2014
Incidences, adaptation, et vulnérabilité

Partie A: Aspects mondiaux et sectoriels
Part B: Aspects régionaux

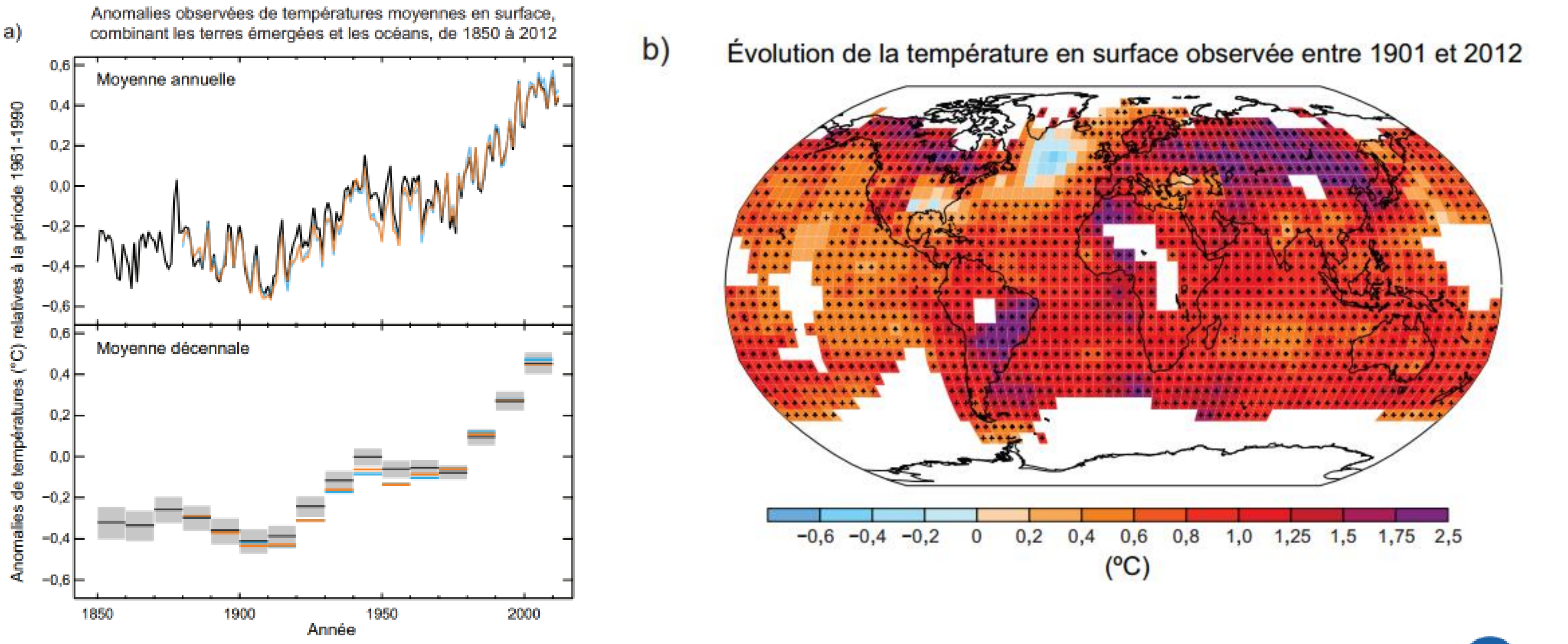
Contribution du Groupe de travail II
au cinquième Rapport
d'évaluation du GIEC

Résumé à l'intention des décideurs
Résumés, foire aux questions et encarts thématiques
(disponible en anglais seulement)
Rapport (version définitive)

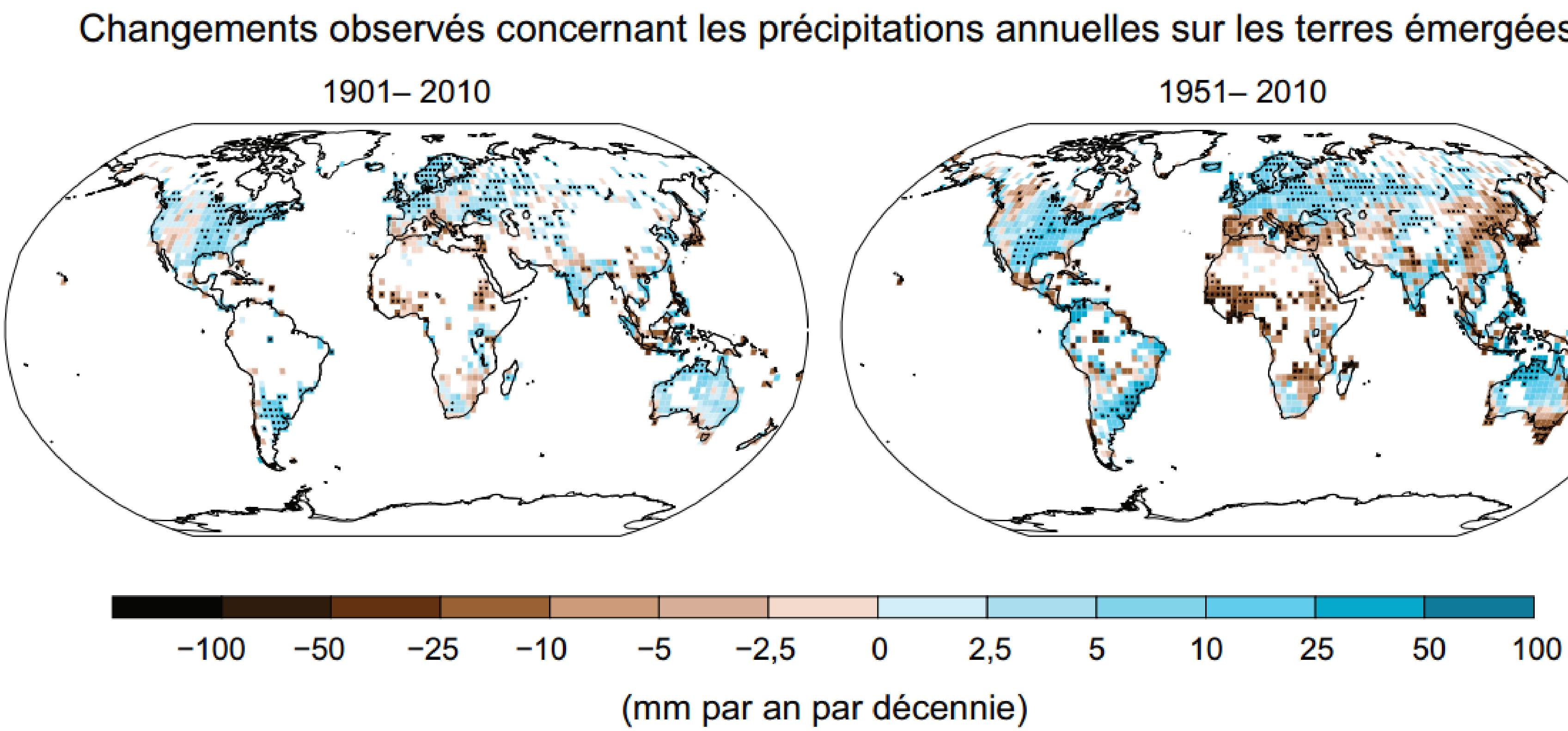
http://www.ipcc.ch/home_languages_main_french.shtml

Changements observés dans le système climatique

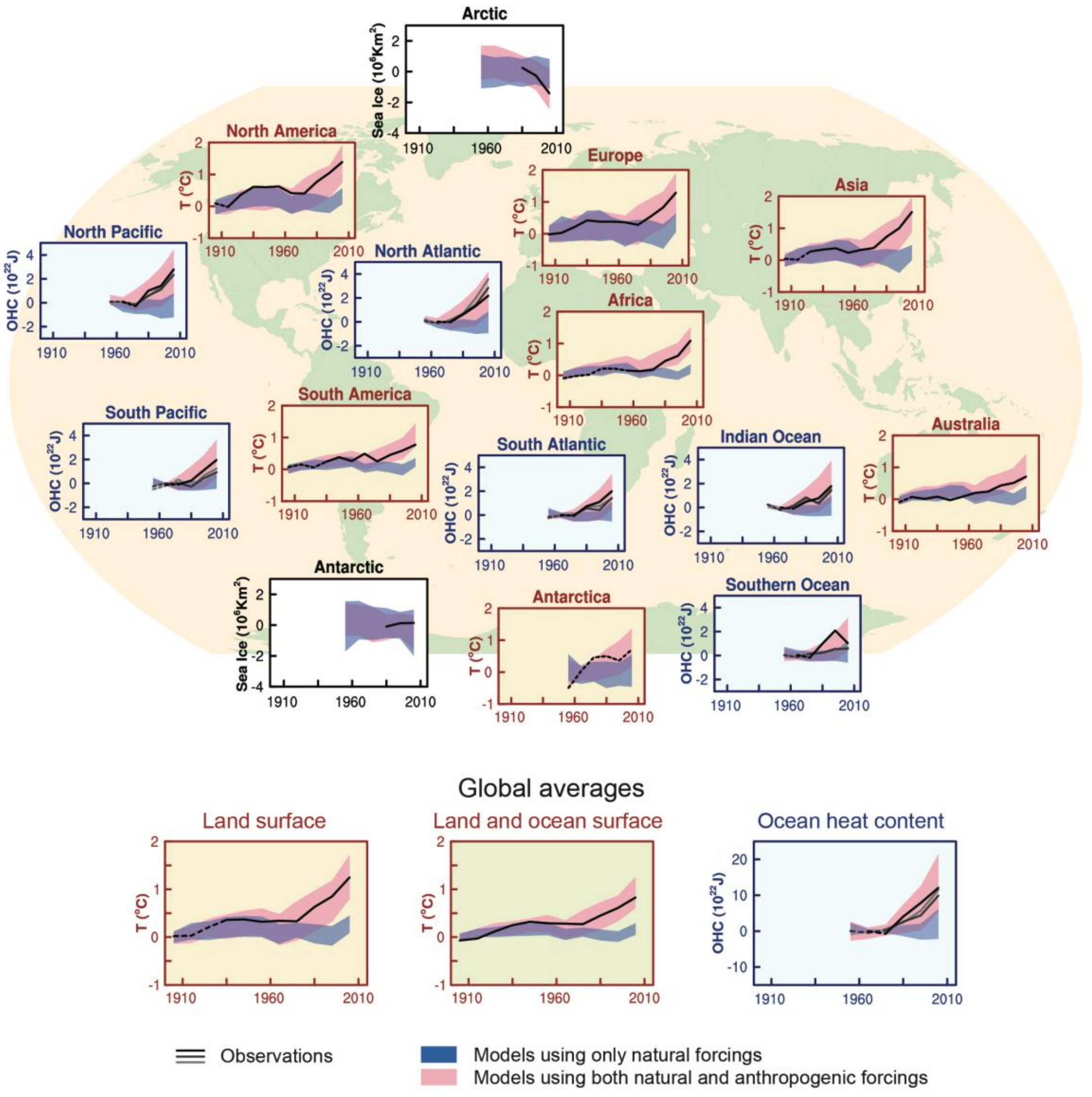
Le réchauffement du système climatique est sans équivoque et, depuis les années 1950, beaucoup de changements observés sont sans précédent depuis des décennies voire des millénaires. L'atmosphère et l'océan se sont réchauffés, la couverture de neige et de glace a diminué, le niveau des mers s'est élevé et les concentrations des gaz à effet de serre ont augmenté.



Changements observés dans le système climatique

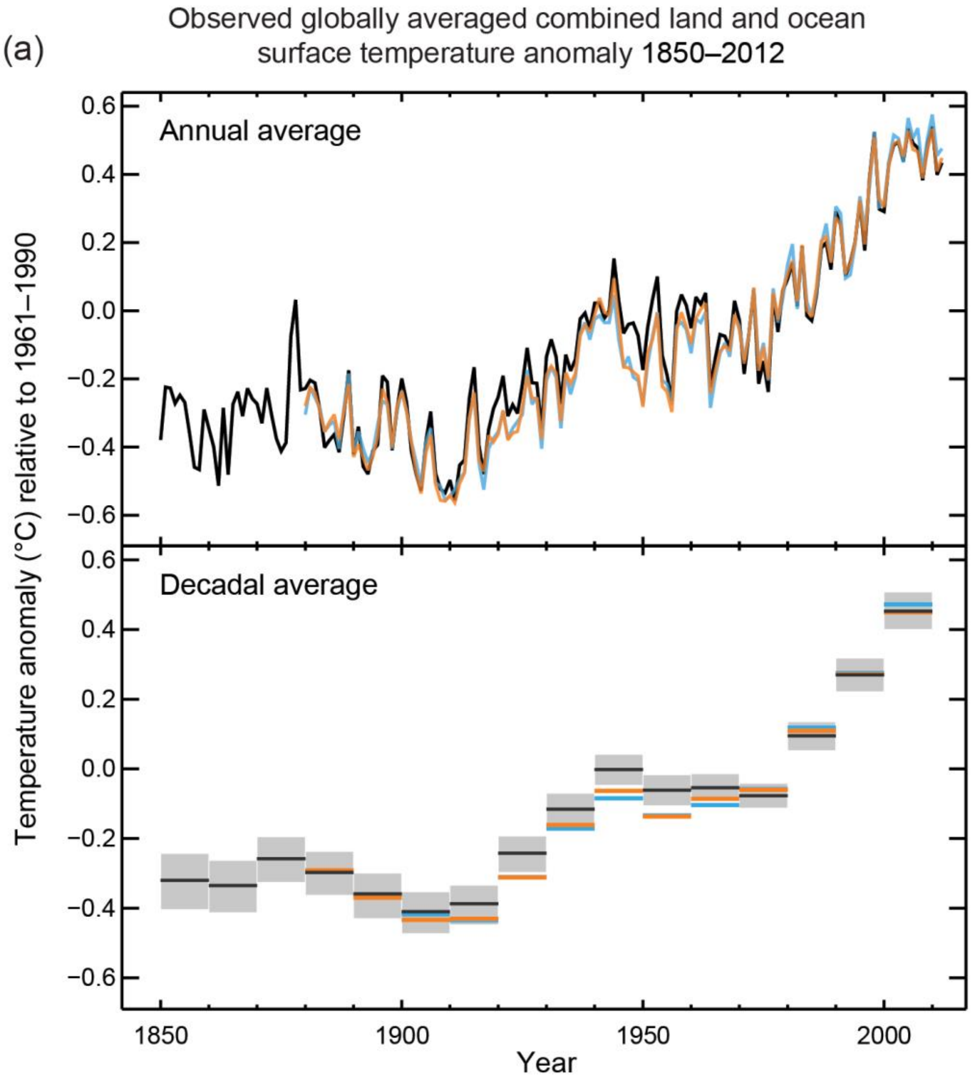


Cambiamento della temperatura dell'aria sulla superficie continentale terrestre (pannelli gialli), l'estensione del ghiaccio marino artico e antartico in settembre (pannelli bianchi), e il contenuto di calore dell'oceano superficiale, nei principali bacini oceanici (pannelli blu). Sono inoltre forniti i cambiamenti globali medi

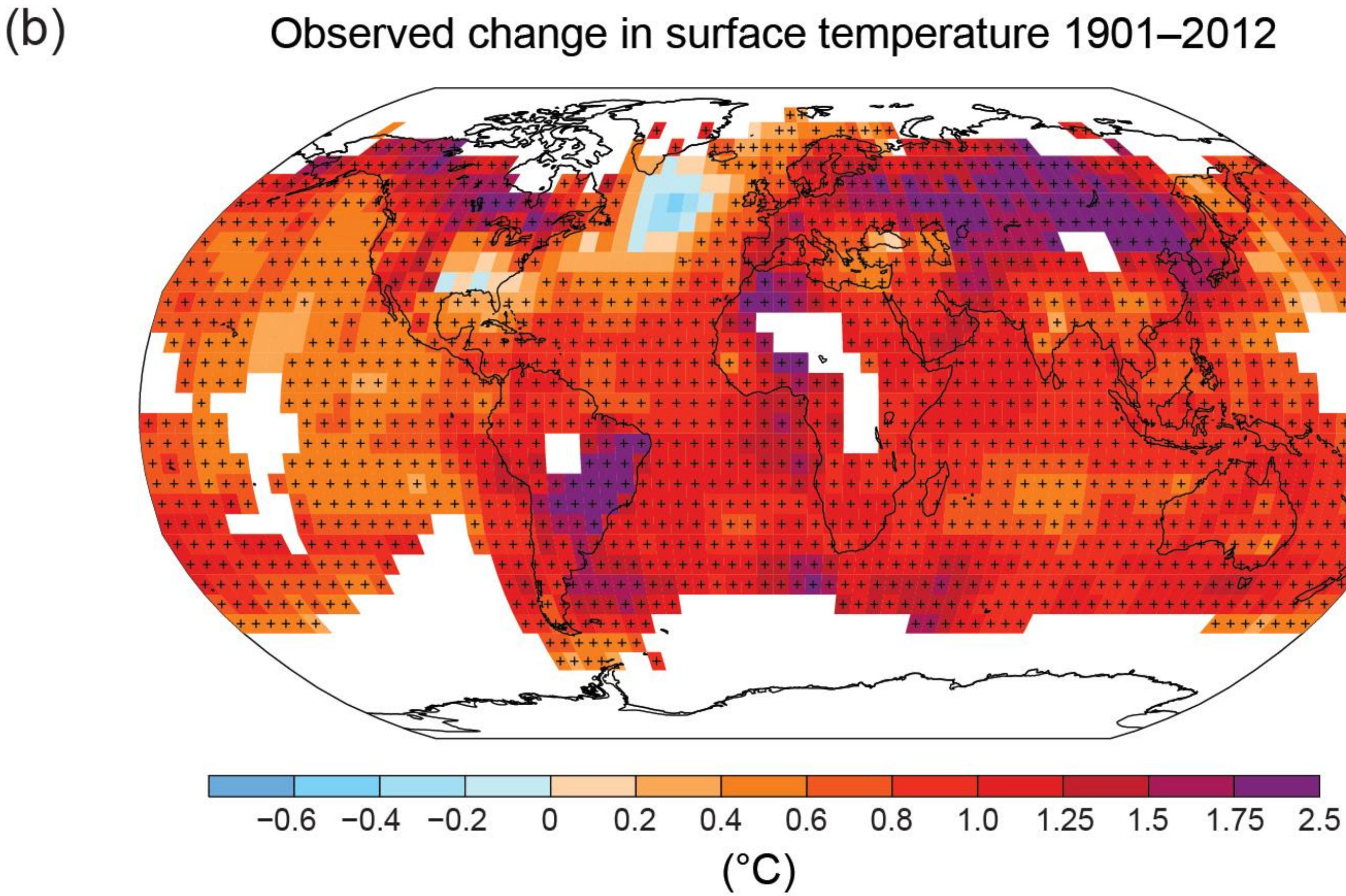


Riscaldamento globale

La temperatura atmosferica superficiale mostra che ciascuno degli ultimi tre decenni sulla superficie della Terra è stato in sequenza più caldo di qualsiasi decennio precedente dal 1850



Riscaldamento globale

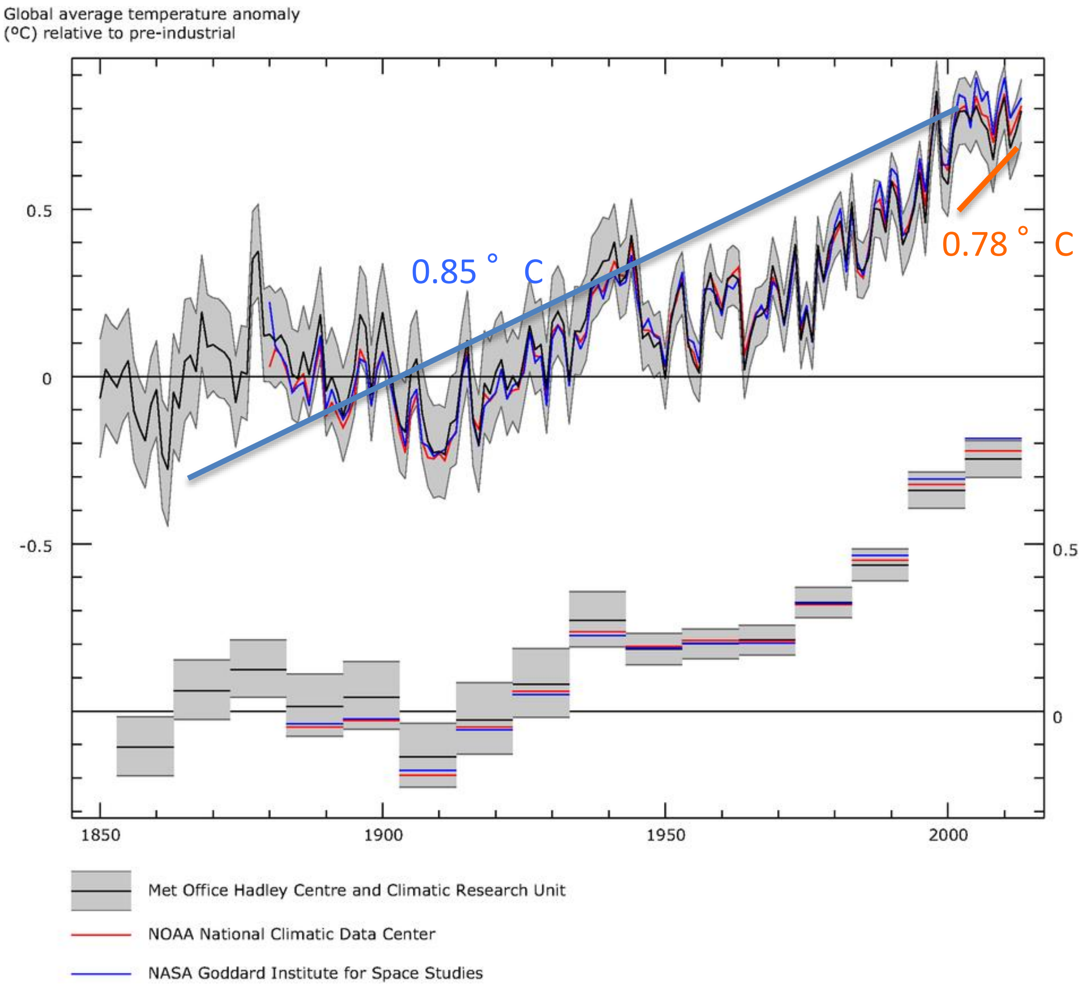


Nell'emisfero settentrionale, il periodo 1983-2012 è stato probabilmente il trentennio più caldo degli ultimi 1400 anni

Riscaldamento globale

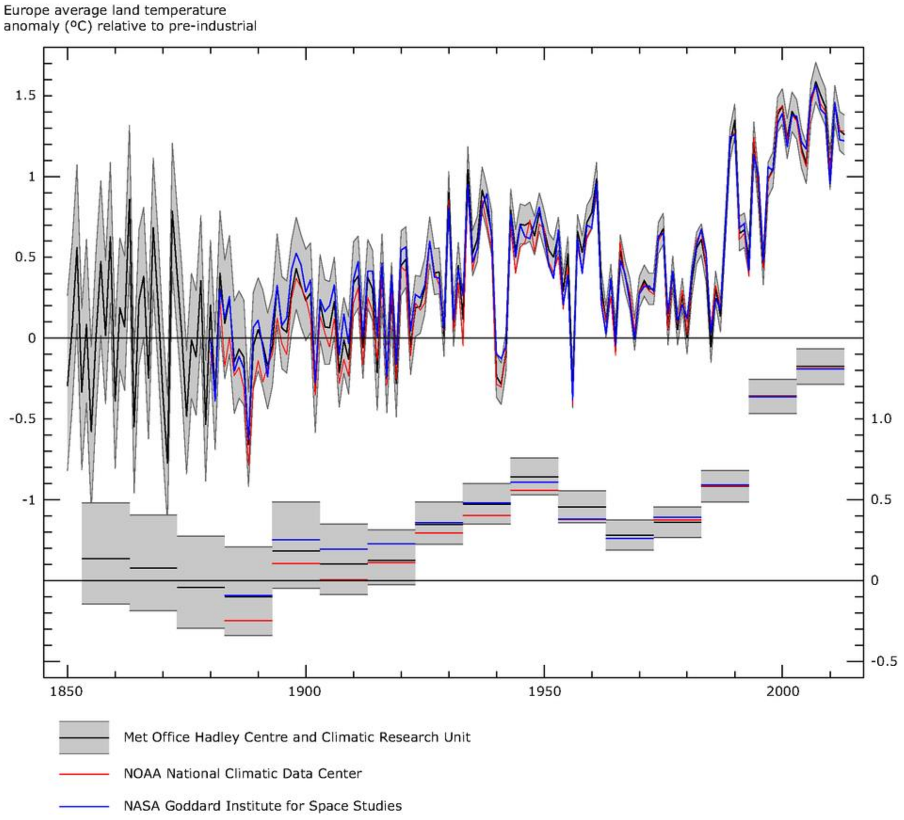
Temperatura superficiale media globale di terra e oceano mostrano un riscaldamento pari a **0.85** [0.65-1.06] °C nel periodo 1880-2012

L'incremento totale considerando la media del periodo 1850-1900 e quella del periodo 2003-2012 è **0.78** [0.72-0.85] °C



Riscaldamento globale

La temperatura superficiale media per **l'area europea** per l'ultimo decennio (2004-2013) è di 1.3 ° C al di sopra del livello pre-industriale, che lo rende il decennio più caldo mai registrato



Fonte: eea, http://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature/global-and-european-temperature-assessment-8

Riscaldamento globale

Il 2005 e il 1998 sono stati gli anni più caldi dal 1850

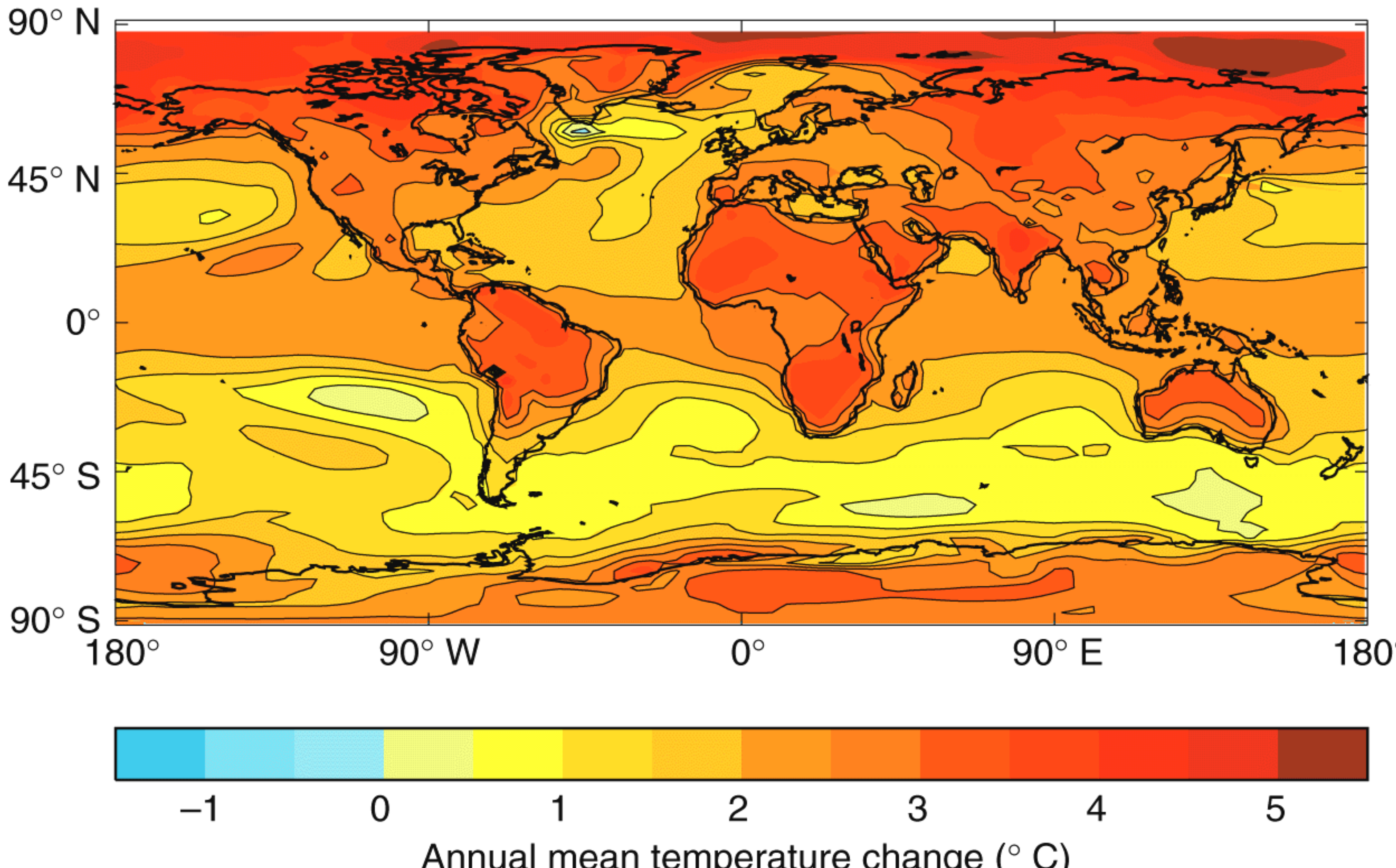
11 su 12 anni nel periodo 1995-2006 si classificano fra i più caldi mai registrati da quando si hanno misure globali di temperatura superficiale (1850)

- ❑ Aumento a scala globale + 0,85° C
- ❑ Aumento a scala europea + 1.3° C

- ✧ Proiezione a scala globale (2100) + 1.5-4.1 ° C
- ✧ Proiezione a scala europea +2.4-4.1° C

Cambiamento temperature globali al 2050

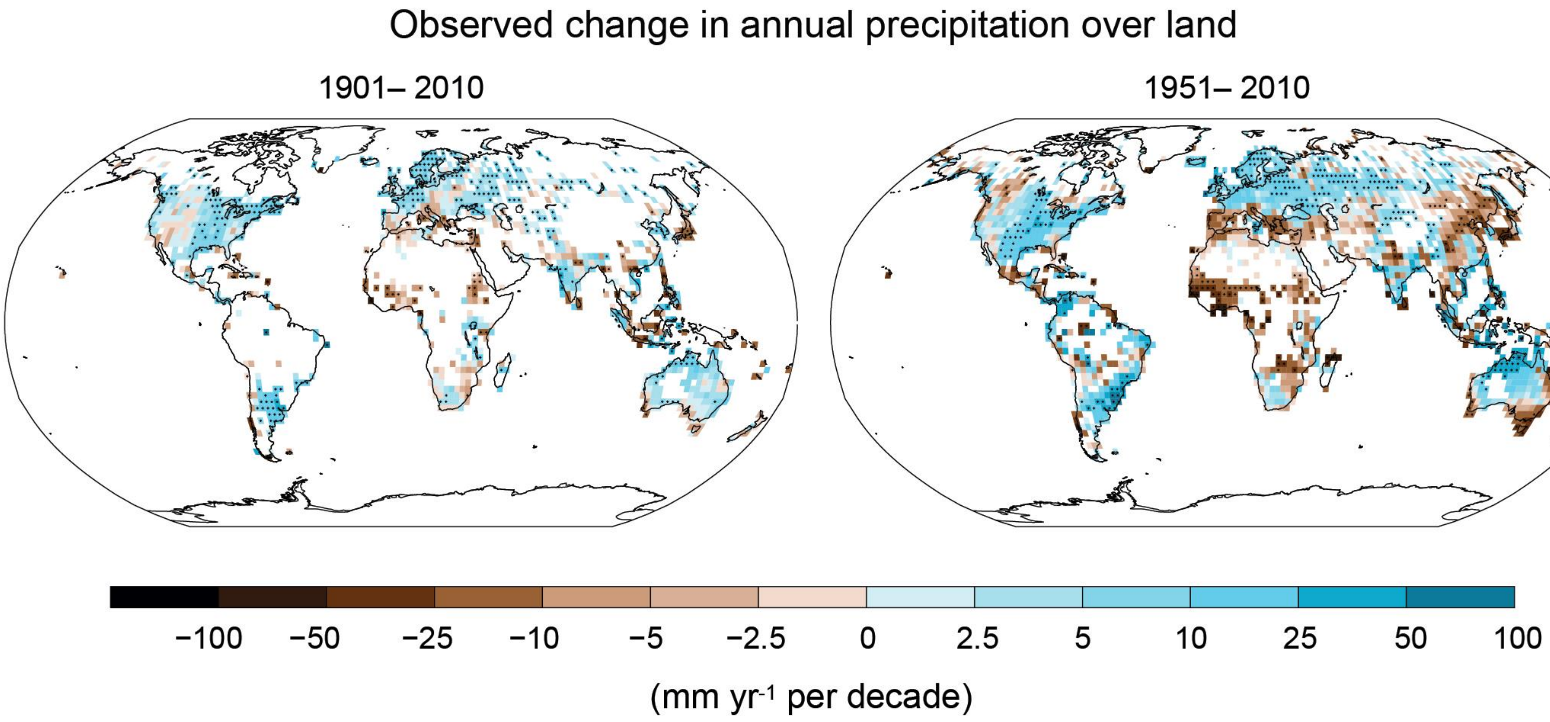
Hadley Centre for Climate Prediction and Research



The change in annual temperatures for the 2050s compared with the present day, when the climate model is driven with an increase in greenhouse gas concentrations equivalent to about a 1% increase per year in CO_2. The picture shows the average of four model runs with different starting conditions.

Precipitazioni

Alle medie latitudini le precipitazioni sono aumentate dal 1901



Livello confidenza *media* prima del 1951, confidenza *alta* dopo il 1951

Precipitazioni

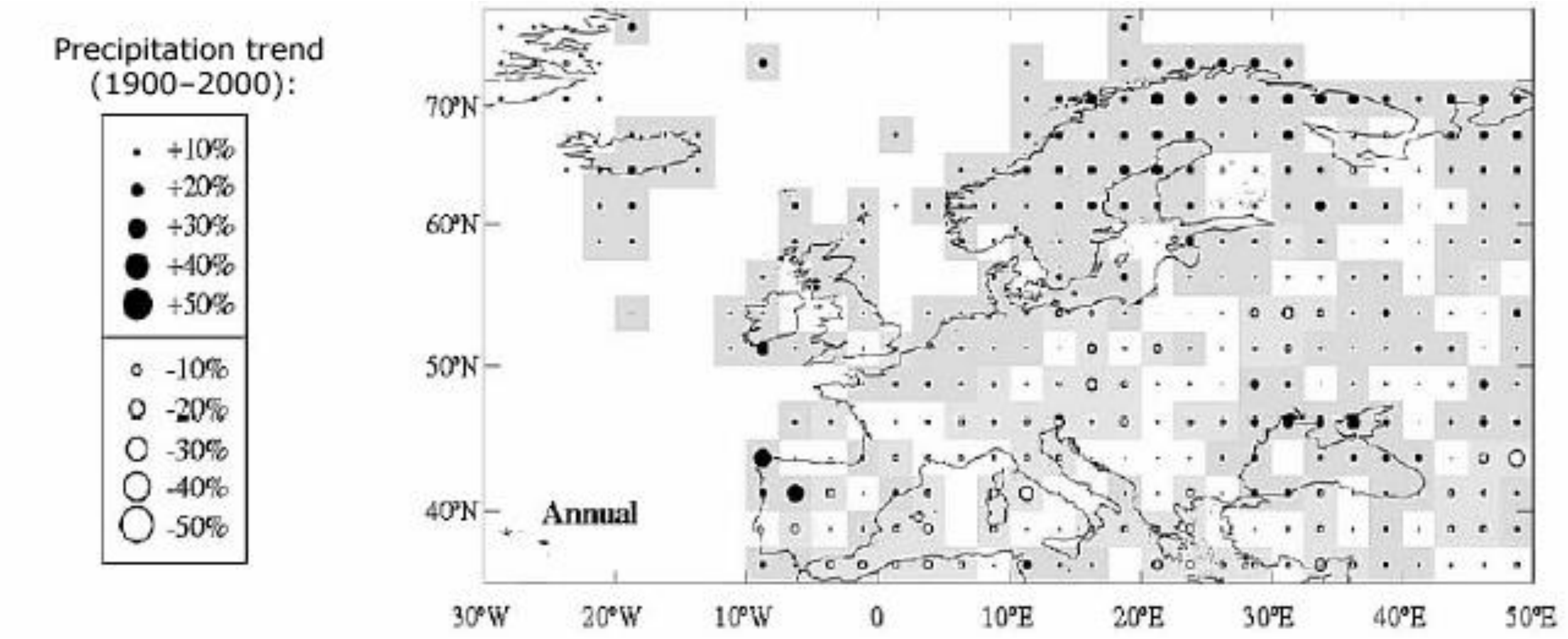
Trend globale eterogeneo

- Incremento di eventi di forte precipitazione in Nord America e in Europa
- Tendenza alla siccità nel Sahel, nel Mediterraneo, nell’Africa meridionale e in parti dell’Asia meridionale

Precipitazioni

Trend europeo eterogeneo (1900-2000)

- Nord Europa +10-40%
- Sud Europa fino al 20% in meno

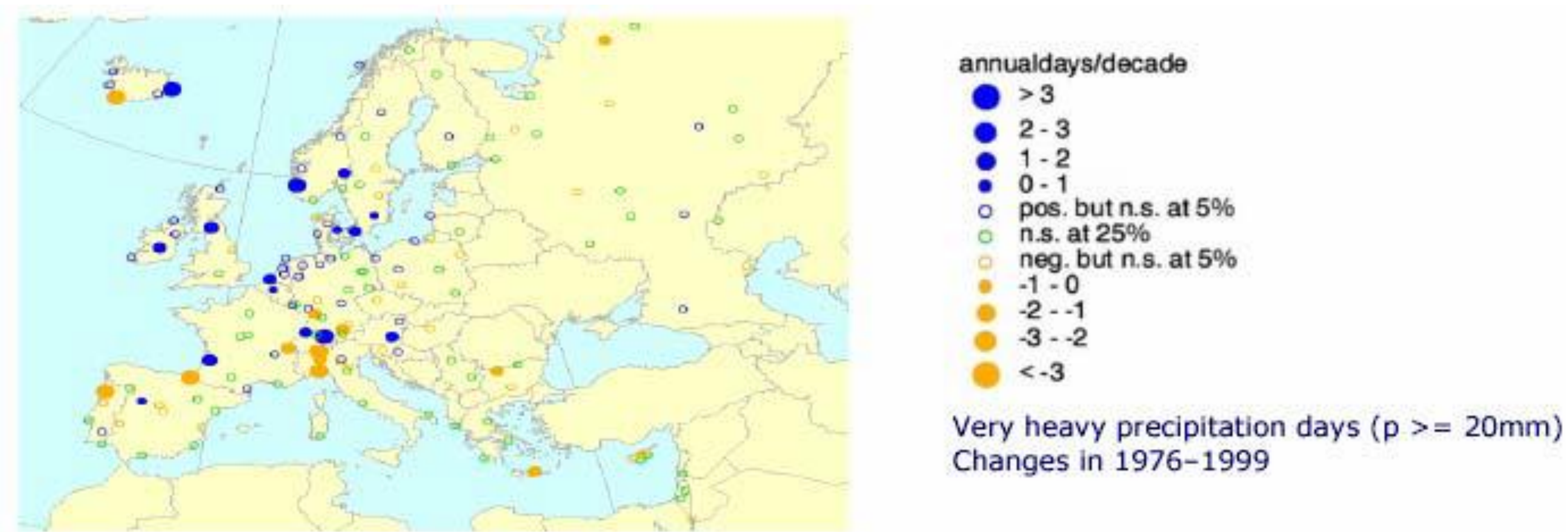


- +1-2% ogni decade Nord Europa
- Fino a -1% ogni decade sul sud Europa

Giorni con precipitazioni ≥ 20 mm

Trend eterogeneo (1976-1999)

- Incremento nel nord Europa
- Decremento nel sud Europa



Probabile incremento degli eventi siccitosi e alluvionali

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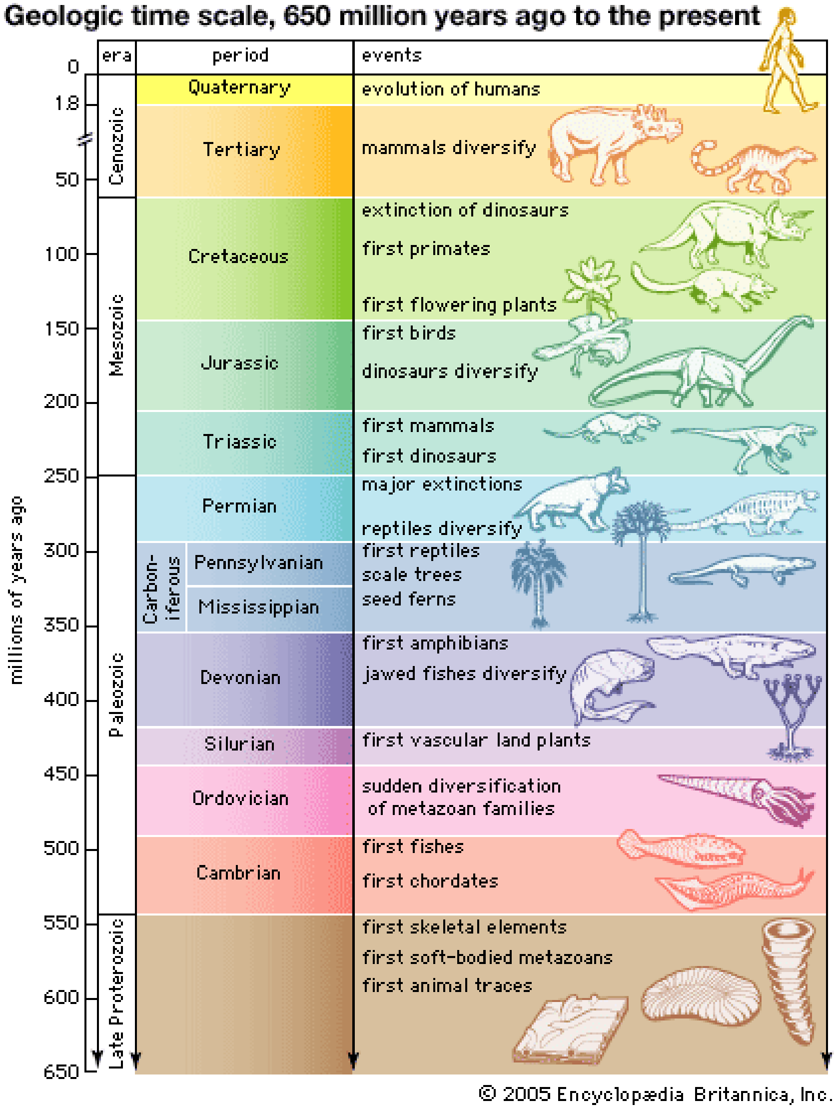
3. Le régime d’incendie

Les incendies dans un contexte globale



Fires have always been in the history of life:

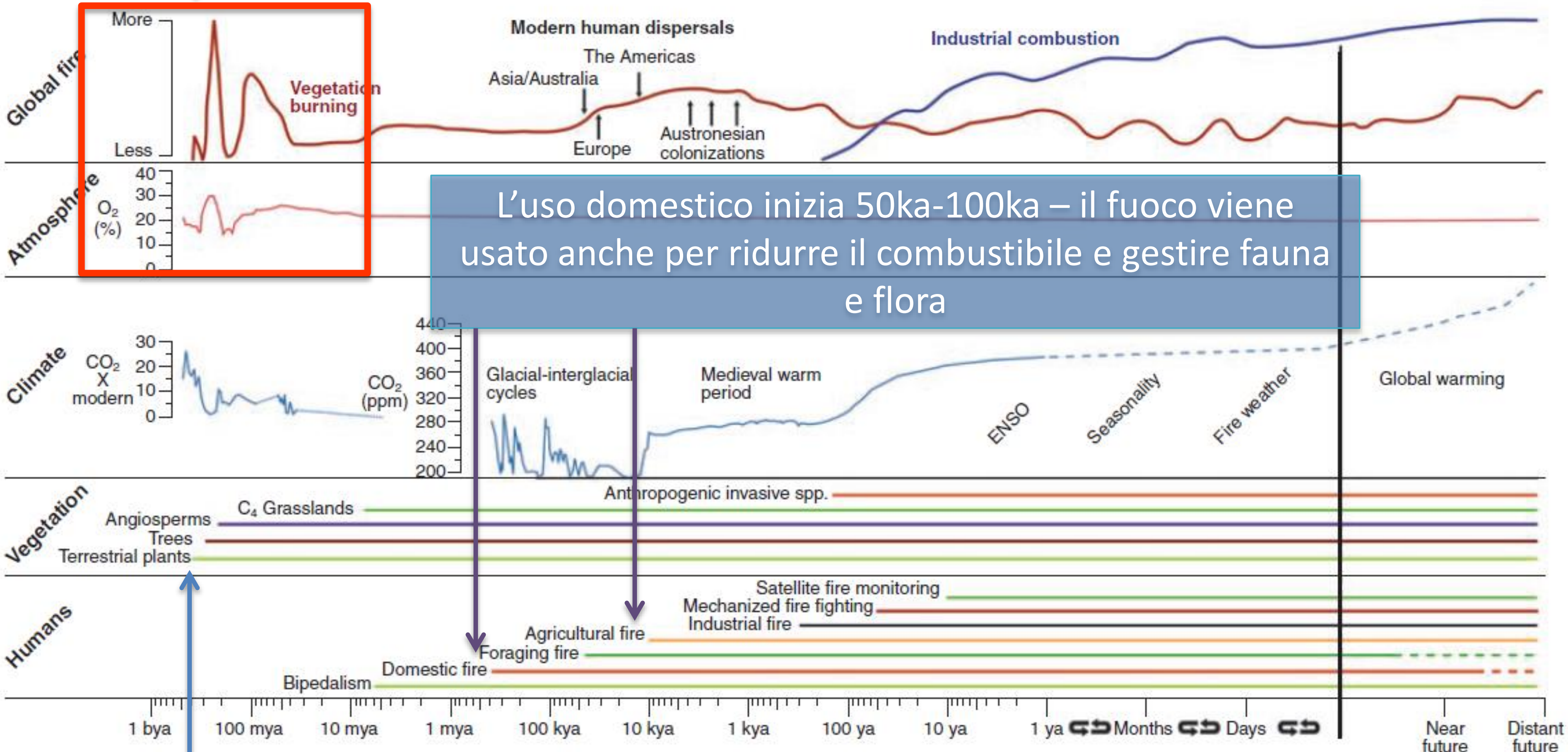
Jurassic gymnosperm forests with high frequency and light surface fires (Francis,1984)

Carboniferous fires in progymnosperm communities (Falcon-Lang, 2000)

Understory surface in Devonian progymnosperm Forests (Cressler 2001)

Fire in the Global Context

La combustione ha origine quando O_2 > 13%

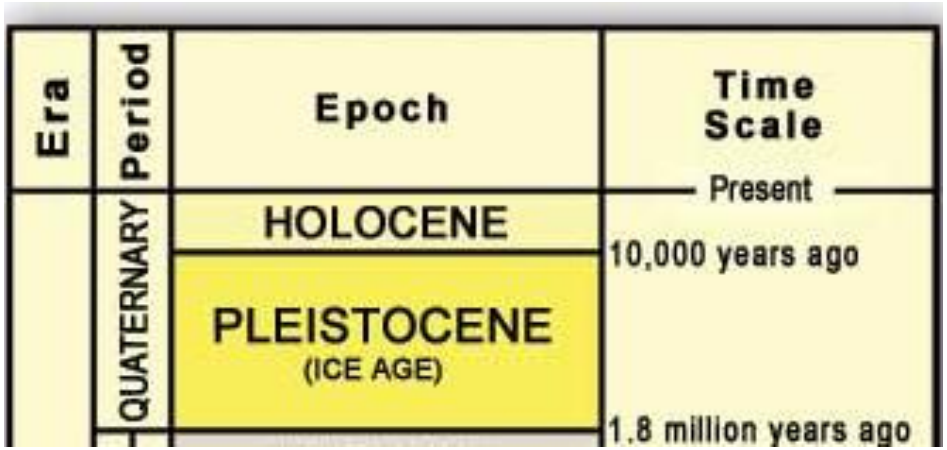


L'uso domestico inizia 50ka-100ka – il fuoco viene usato anche per ridurre il combustibile e gestire fauna e flora

Il carbonio fossile indica che gli incendi iniziarono poco dopo la comparsa delle prime piante terresti (Siluriano, 420 ma)

Bowman et al. 2009 Science

Les incendies et le monde pre-industriel

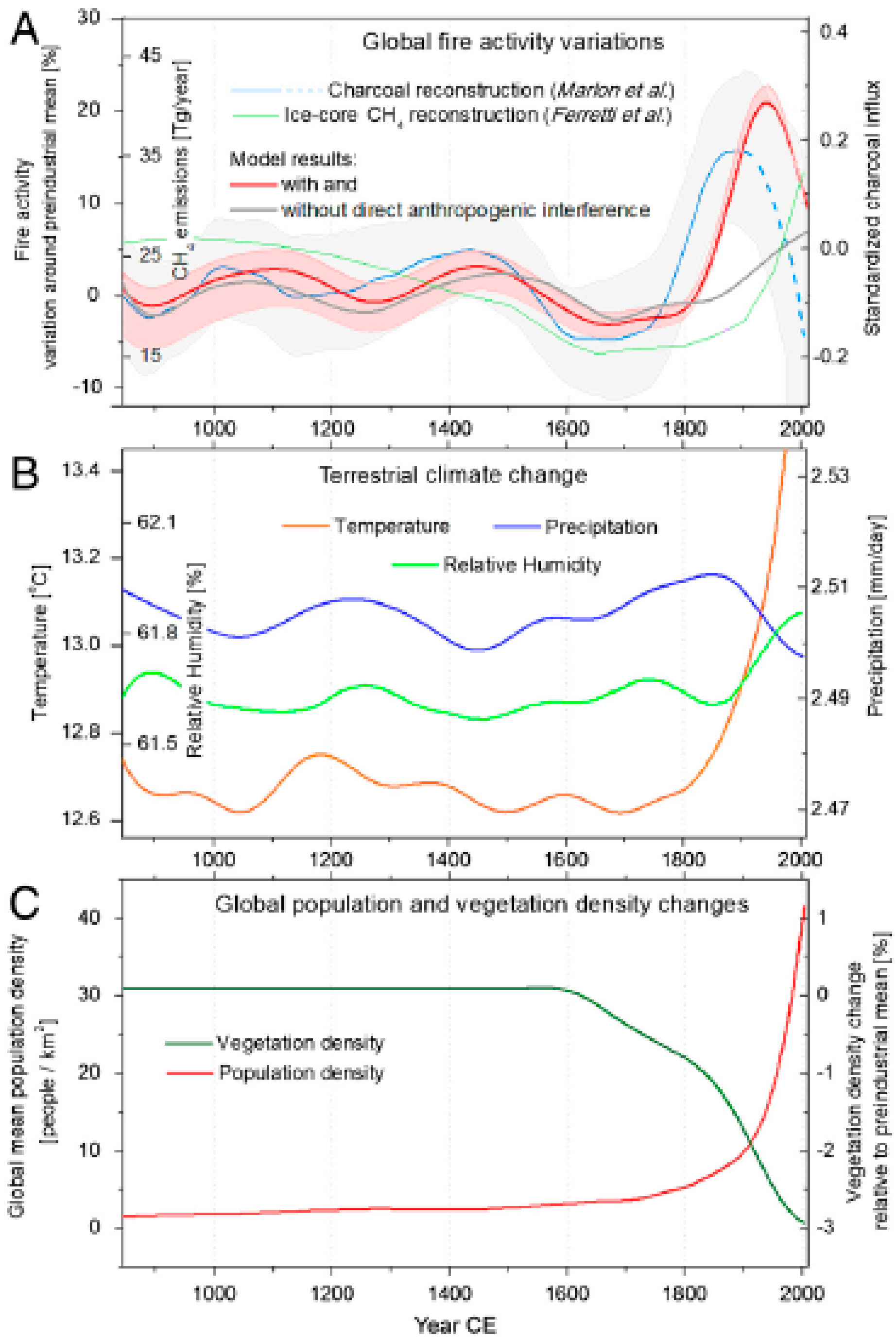


Evidence in the Near East during the Early-Middle Pleistocene (0.79 mya; Goren-Inbar et al. 2004).

Evidence of the controlled use of fire by *Homo erectus in Africa* during the Lower Pleistocene (James 1989), about 1.5 mya.

Quaternary

- Mediterranean Climate -> Dry and warm summer
- Humans -> hunthers and agrarian
- Fire-stick farming: clearing ground for human habitats, facilitating travel, killing vermin, hunting, regenerating plant food sources for both humans and livestock, and even warfare among tribes (Bird et al., 2008)



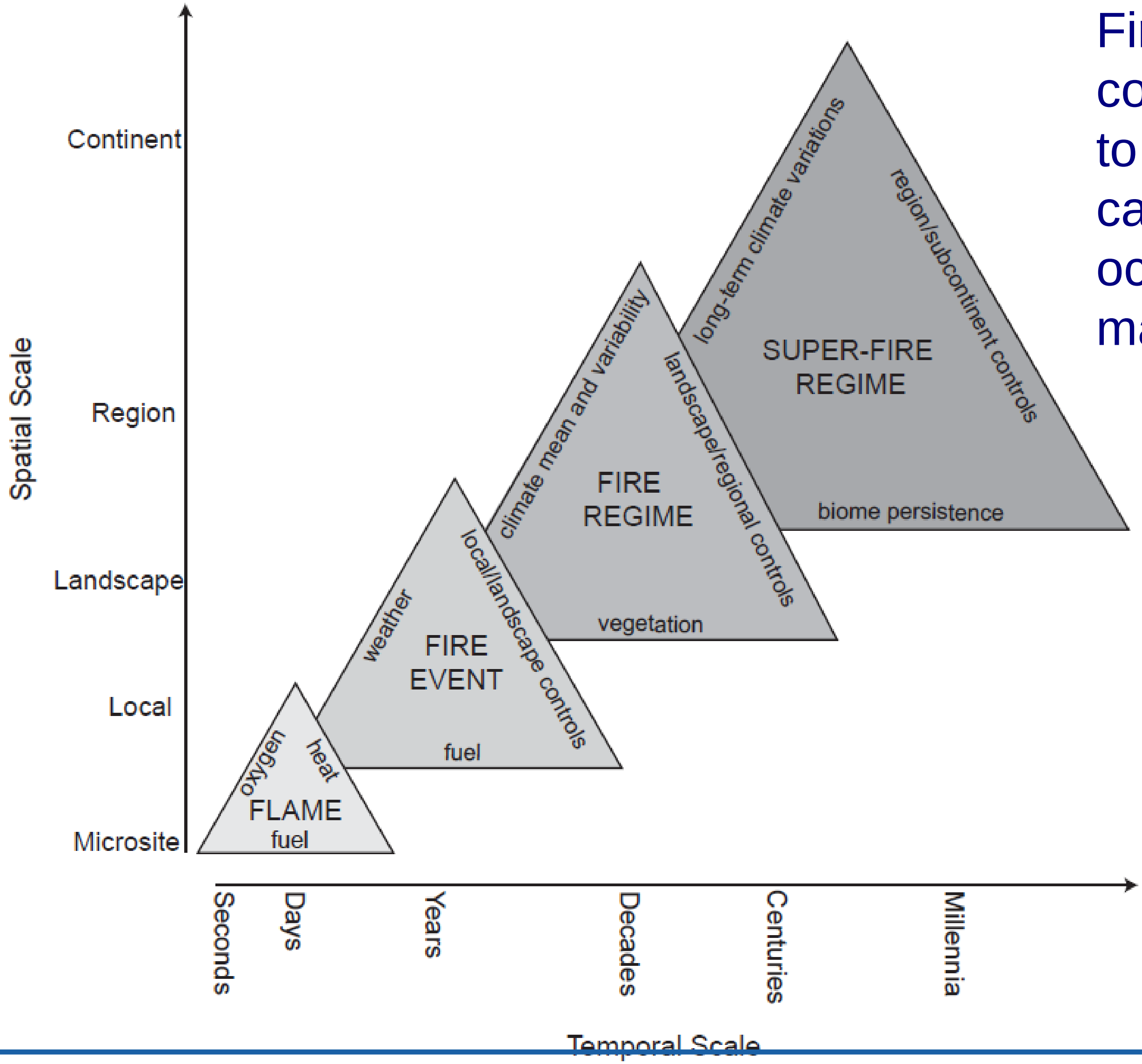
Fires and the modern world

- ➢After Industrial Revolution human population expanded rapidly (Fig. 1C).
- ➢Unprecedented rates of fossil fuel burning led to the onset of global warming (Fig. 1B).
- ➢Over the 19th century both the model- and the charcoal-based records show sharp increases in biomass burning (Fig. 1A).

Model results suggest a stronger influence from direct anthropogenic activities

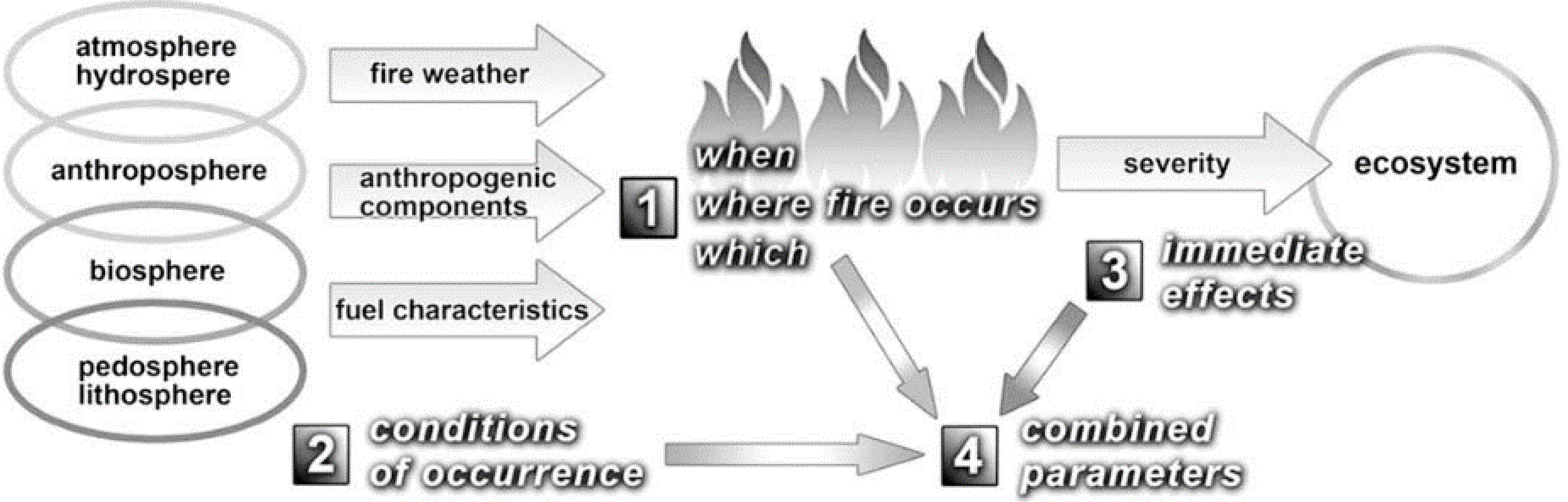
Source: Pechony and Shindell, 2010

Fire Regime



Fire regimes are a convenient and useful way to classify, describe, and categorize the pattern of fire occurrence for scientific and management purposes.

Fire Regime

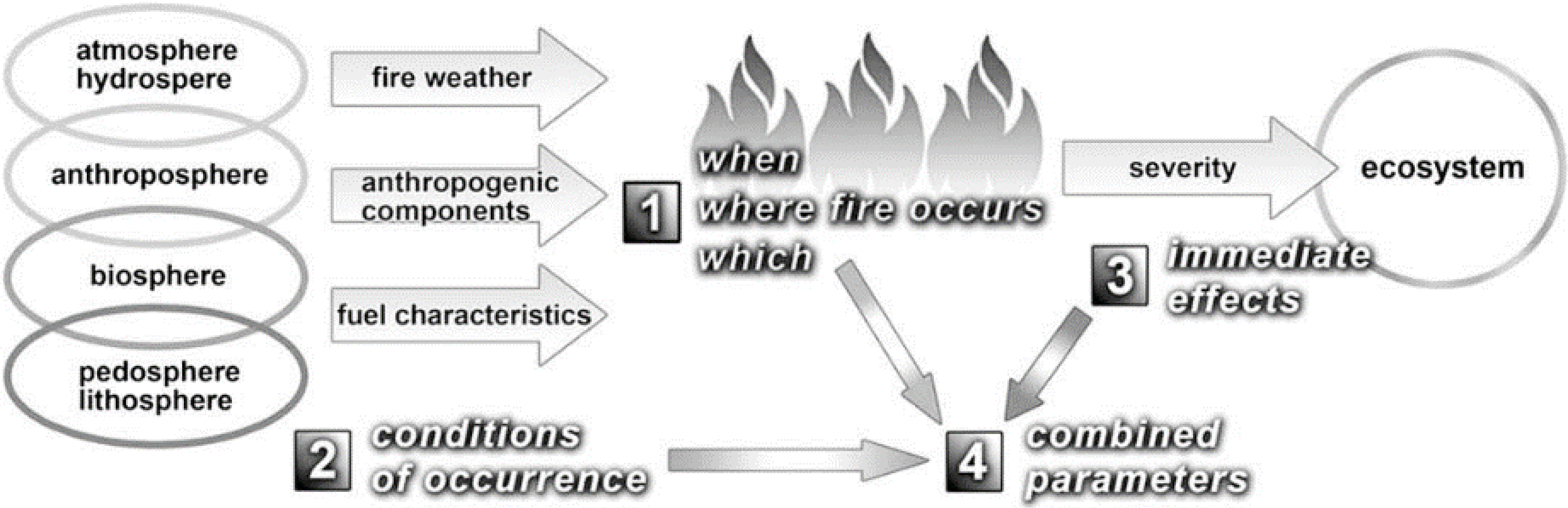


[1] core components (fire regime *sensu strictu*) describing **which** fire (type, intensity, fire behavior, etc.), **when** (frequency, seasonality, synchronicity, etc.) and **where** (size, shape of fires, etc.) it occurs.

[2] conditions controlling fire occurrence (fire weather, wind regime, ignition sources, fuel characteristics, flammability, etc.);

Conedera et al., Quaternary Science Reviews (2009)

Fire Regime



[3] immediate fire effects (severity, mortality, costs and damages, etc.);

[4] derived or composite parameters resulting from the combination of two or more basic variables and conceived to represent some complex characteristics of fire occurrence (trends, variations, classifications systems, etc.).

Conedera et al., Quaternary Science Reviews (2009)

Fire Regime

A FRAMEWORK FOR DEFINING FIRE REGIMES

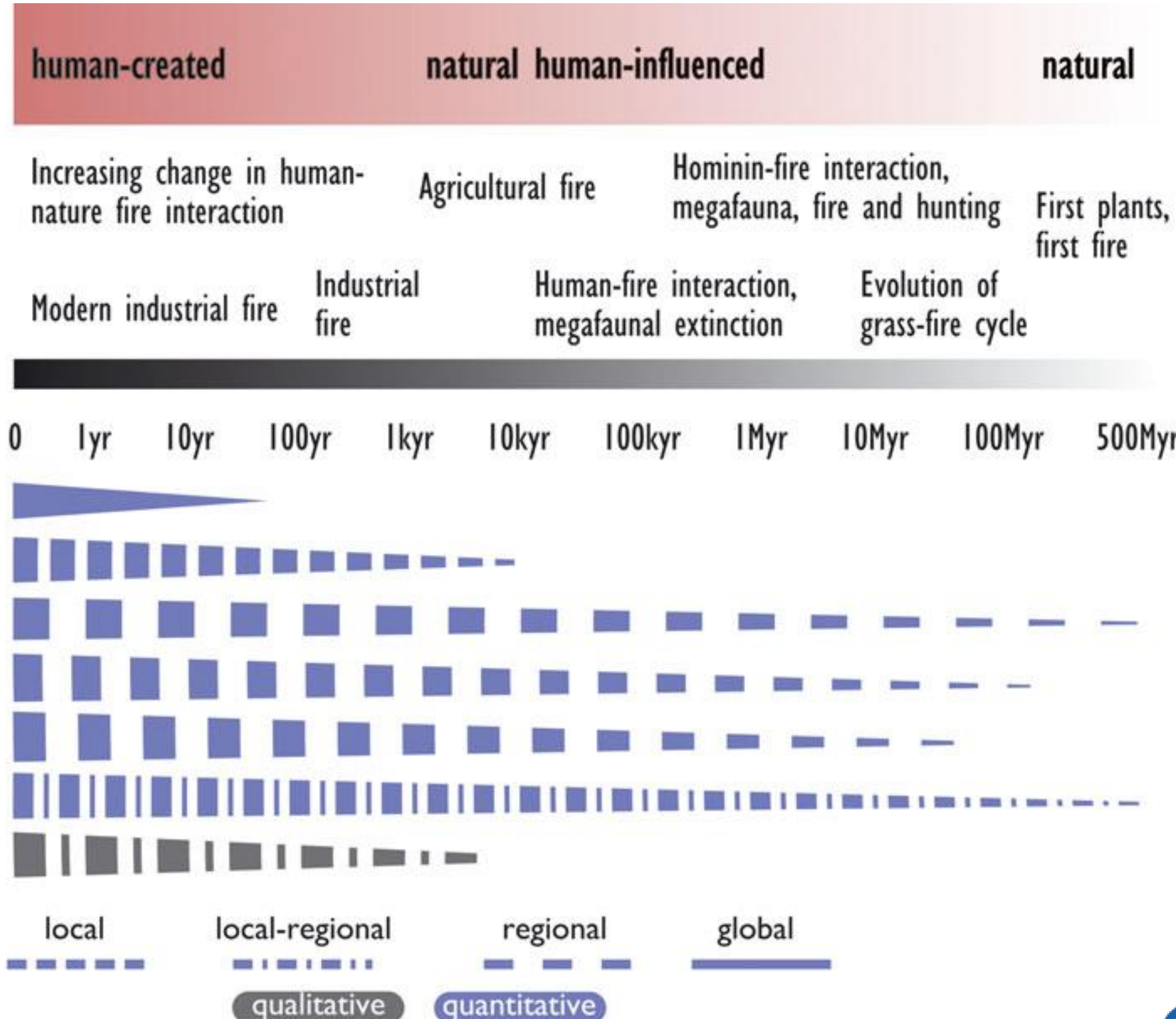
Characteristics	Indicators
Temporal	Seasonality, Frequency, Fire Return Interval
Spatial	Size, Shape Spatial Complexity
Magnitude	Fireline Intensity Fire Severity Fire Type

Data Sources

- Dendrochronology (tree scars from non-lethal fires, cross-dating)
- Paleoecology (charcoal in lake & soil sediments)
- Data bases: reports, aerial photos, maps, atlases, satellite images, remote sensing

Fire Regime

Reconstructing tools



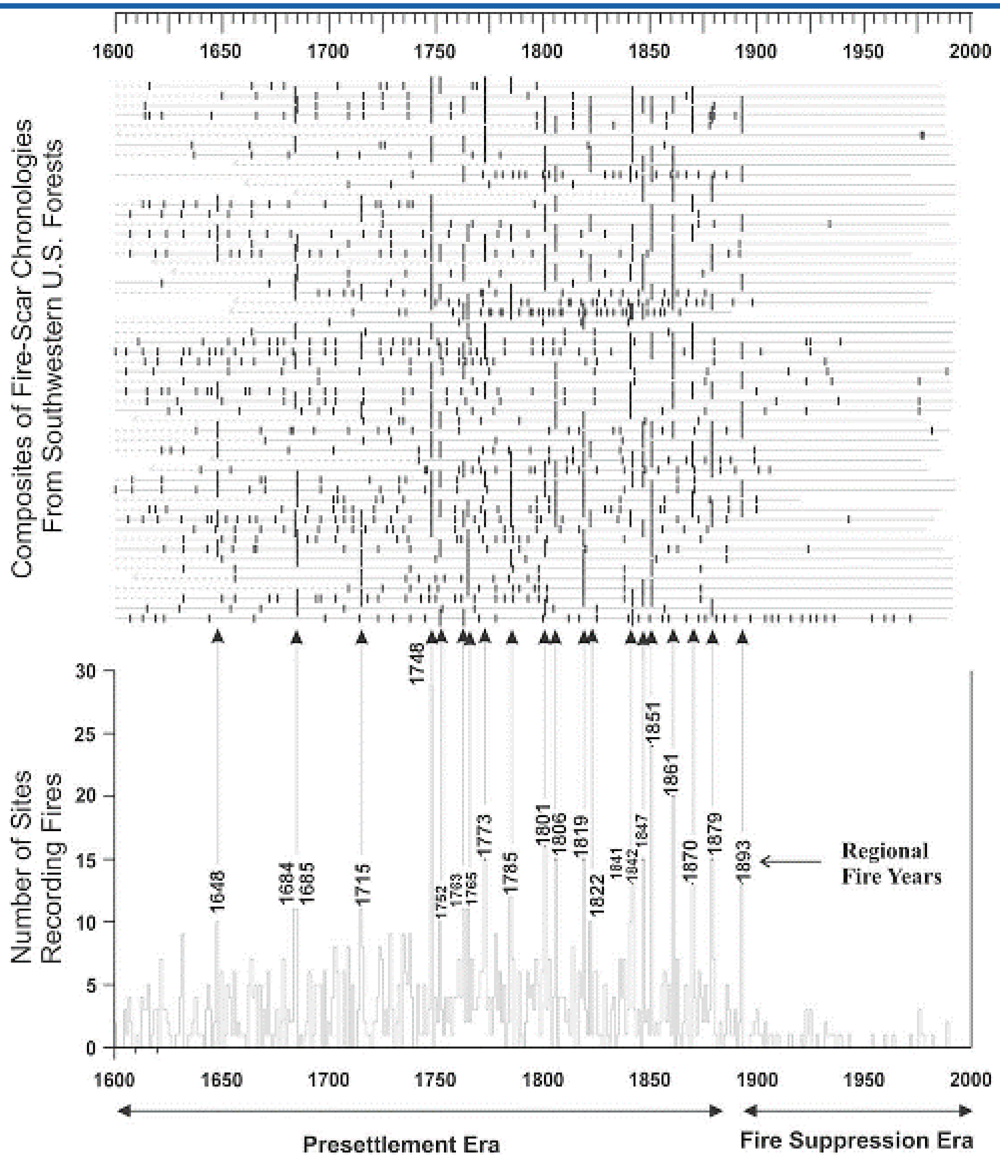
Bowman et al., J Biogeogr. 2011

Fire Regime

Dendrochronology for reconstructing past fire events depends on the capacity of tree species to grow annual rings and to overgrow from fire injuries

Where robust tree ring chronologies exist, fire scars of single trees can be dated with annual precisions by synchronizing their ring sequences with the reference chronology (cross-dating)

Fire Regime



Composite fire scar chronologies from 55 forest and woodland sites in Arizona, New Mexico, and northern Mexico (AD 1600–present)

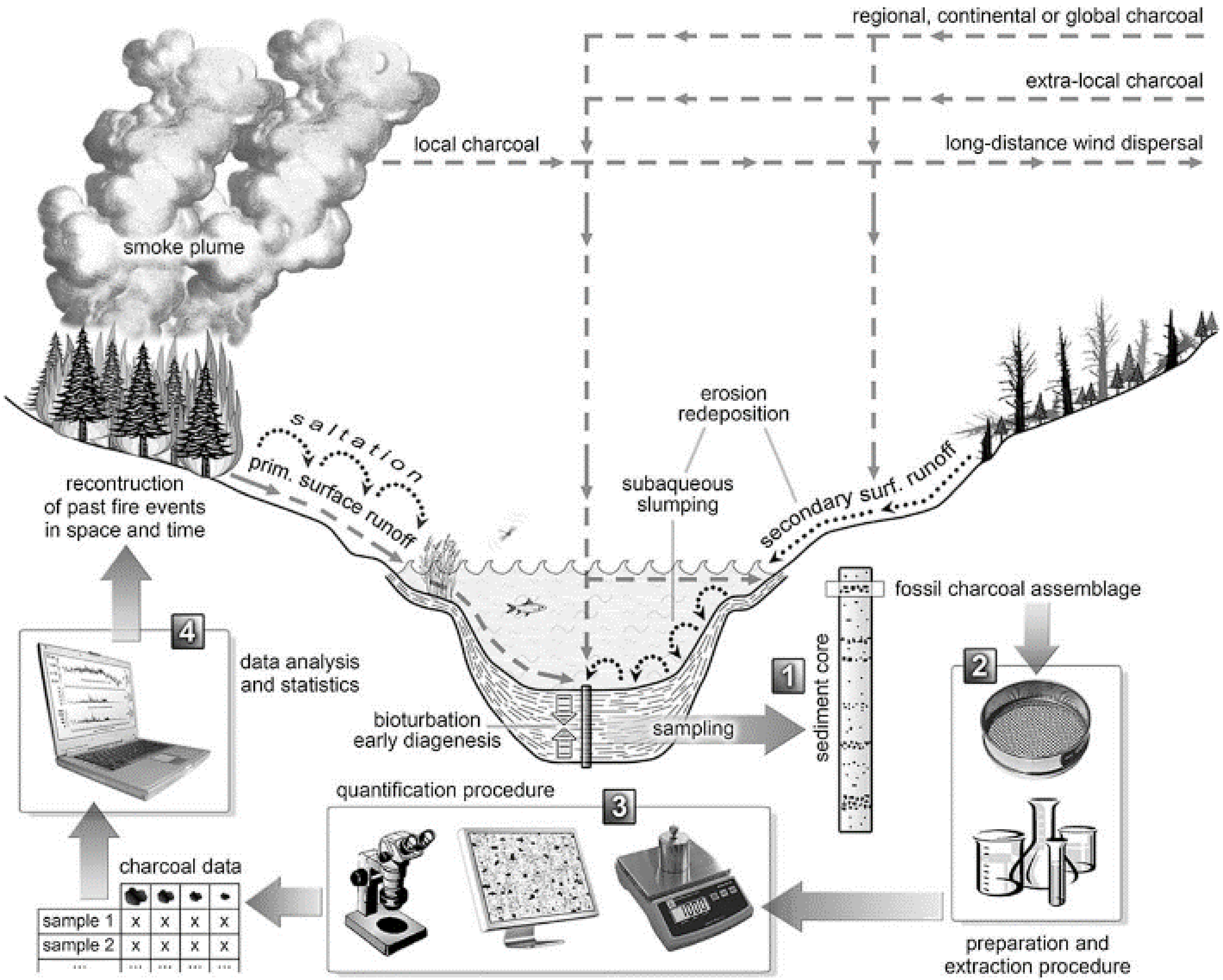
- Each horizontal line = the composite fire chronology from a different site
- Tick marks = the fire dates recorded by 10% fire-scarred trees within that site.
- Long tick marks are fire dates recorded by 10 sites in the southwestern network.

(The average number of trees sampled per site was 20, with a maximum of 56 trees)

Swetnam et al. (1999)

Fire Regime

Reconstructing fire history from lake sediments



Conedera et al., Quaternary Science Reviews (2009)

Fire Regime

Vannière et al. (2011) created regional fire histories from 36 radiocarbon-dated sedimentary charcoal records, available from the Global Charcoal Database. These time series document our current knowledge of Holocene fire history in the Mediterranean basin.

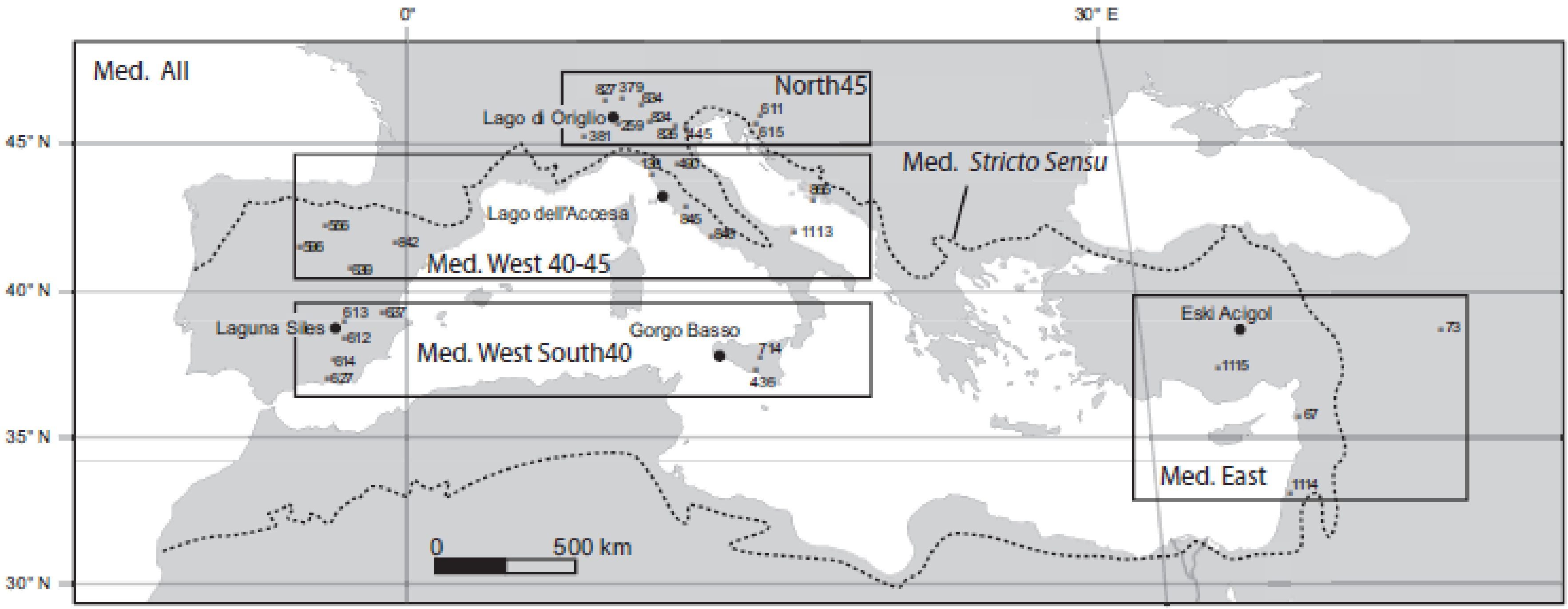
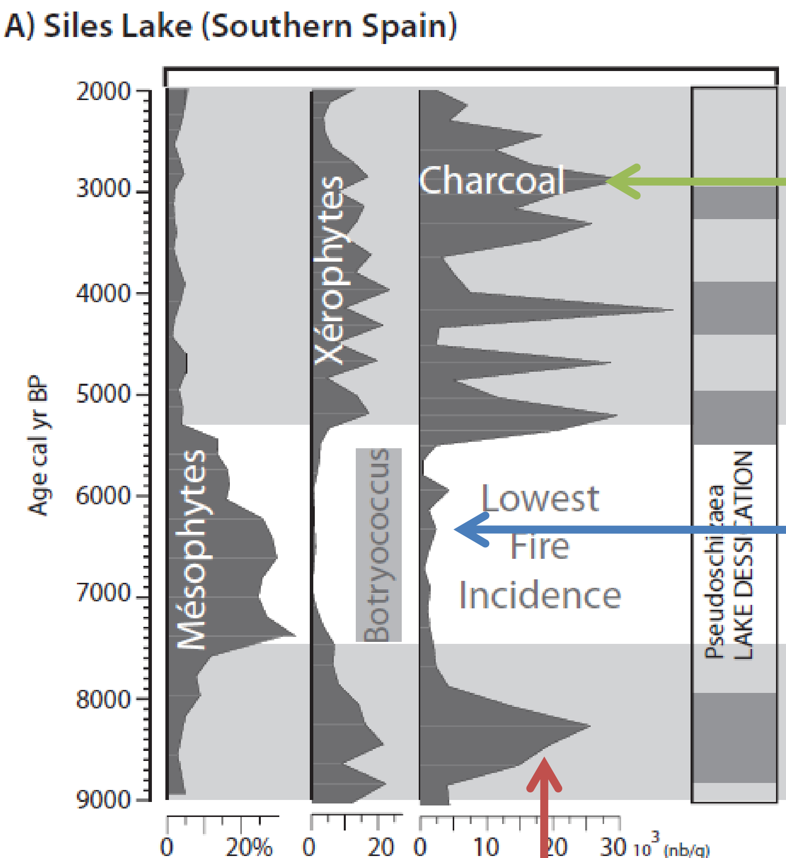


Figure 1. Mediterranean area with the limit (dashed line) of the Mediterranean *stricto sensu* biogeographical zone (Quézel and Médail, 2003), position of sites (see ID/Name in Table 1) used in this study and geographical grouping used for regional syntheses

Fire Regime

Reconstructing fire history from lake sediments



After 2800 cal. BP, all charcoal series available from Spain show a general increase in fire activity.

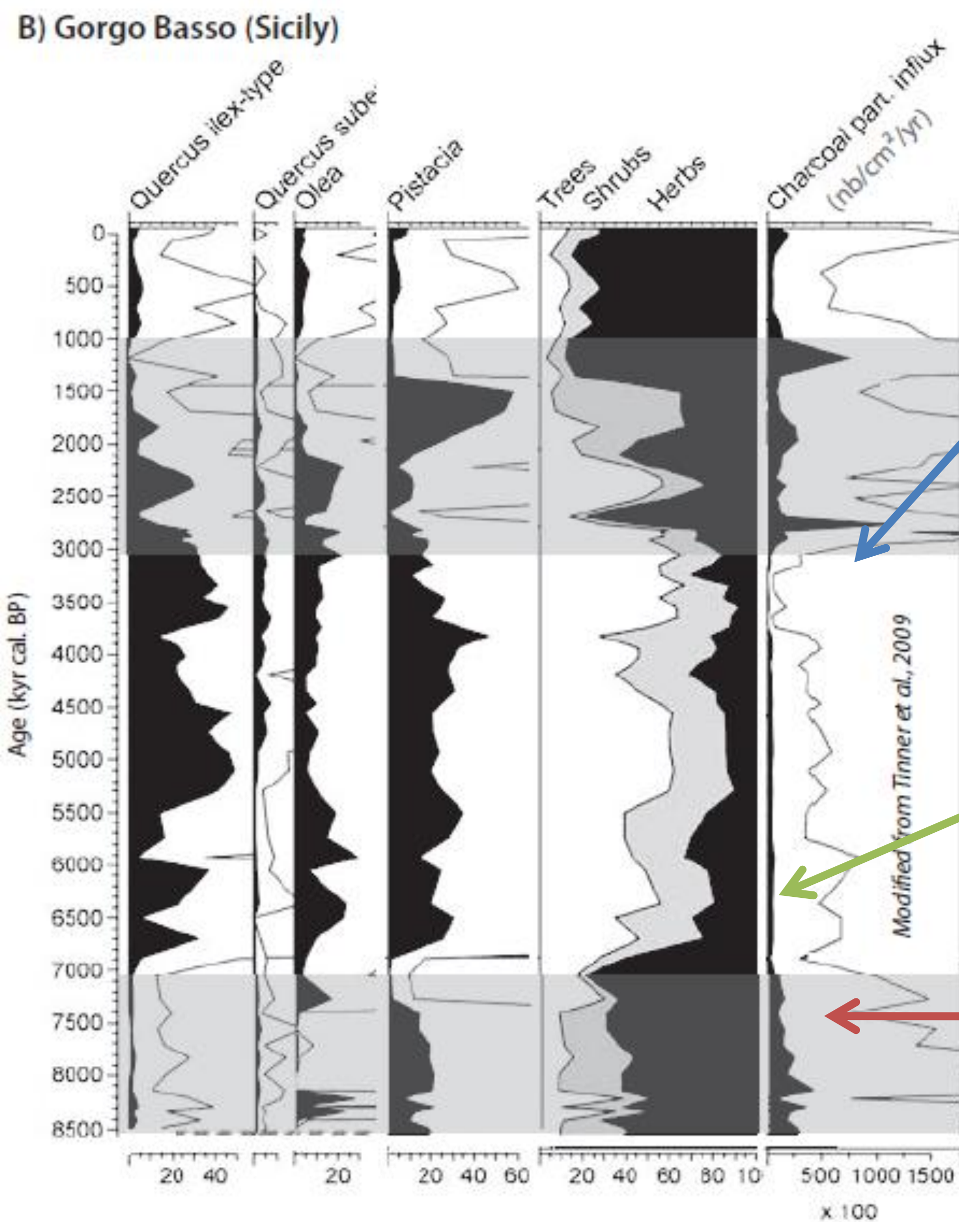
High charcoal influx values have been observed during the period c. 7000–6000 cal. BP, which is coherent with increased aridity in the Ebro Basin during the mid Holocene (González-Sampériz et al., 2009).

A period between 8500 and 8000 cal. BP of high fire activity

Source: Vannière et al. **Holocene 2011**

Fire Regime

Reconstructing fire history from lake sediments

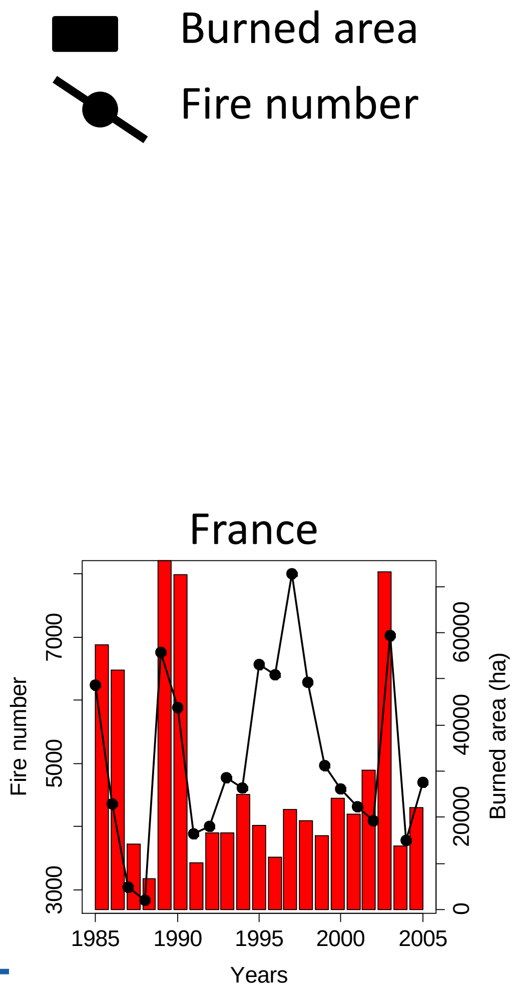


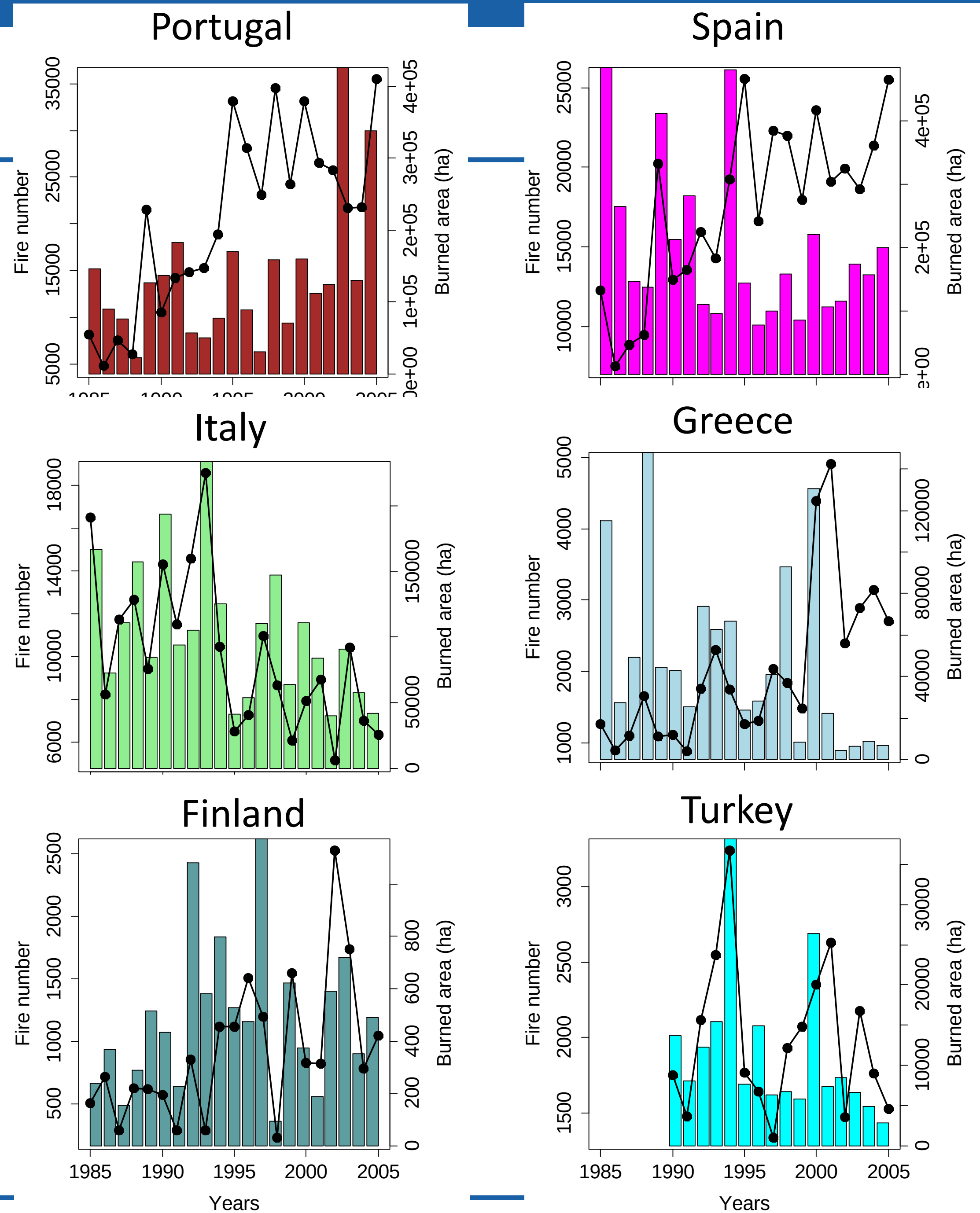
Low fire activity within the rather dense coastal evergreen forests persisted until renewed human activity disrupted these forests and opened the landscape for agriculture

Evergreen broadleaved forest expanded at the expense of open communities and was associated with a lower fire activity as well as a decrease in human activities.

Decline in evergreen Olea europaea woods and an increase in fire activity appear to reflect drier climate conditions

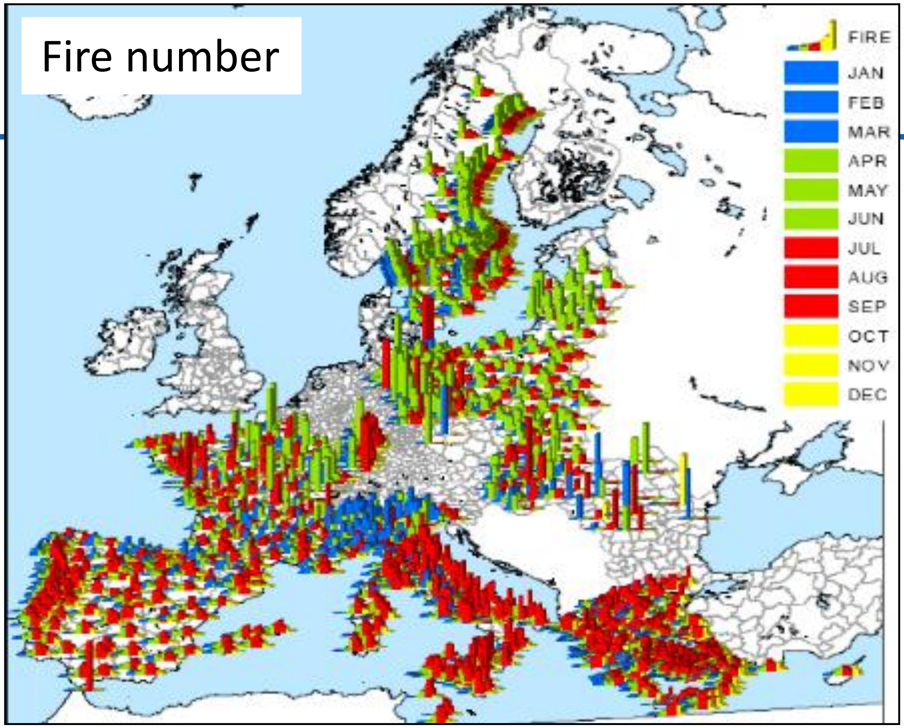
Fire figures

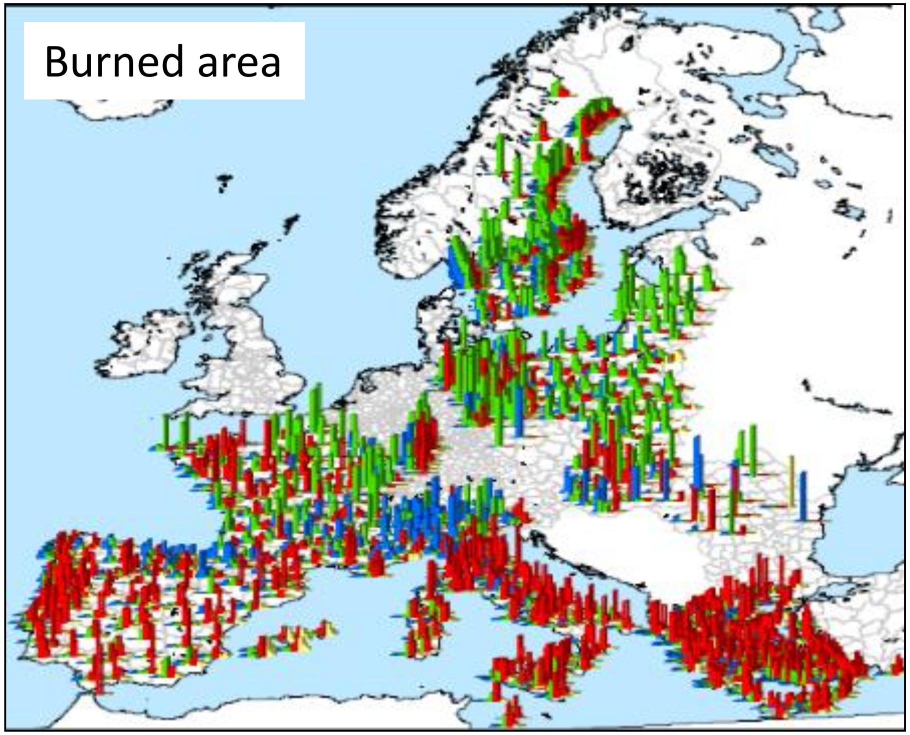




Fire Regime

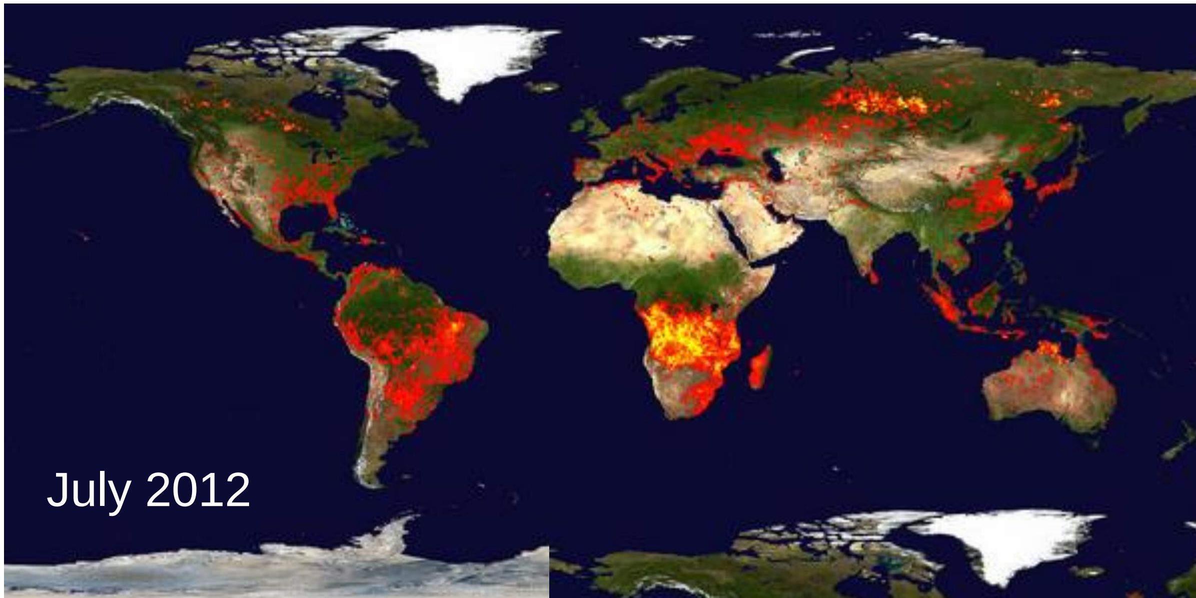
FIRE SEASONALITY
Description of ***when*** fires occur during the year

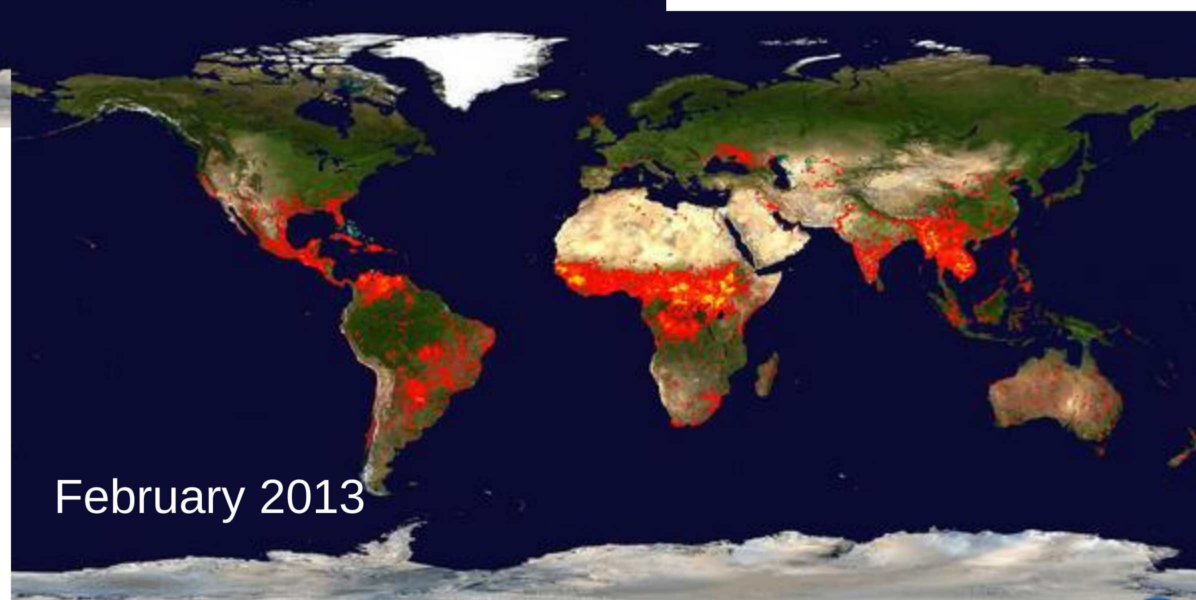




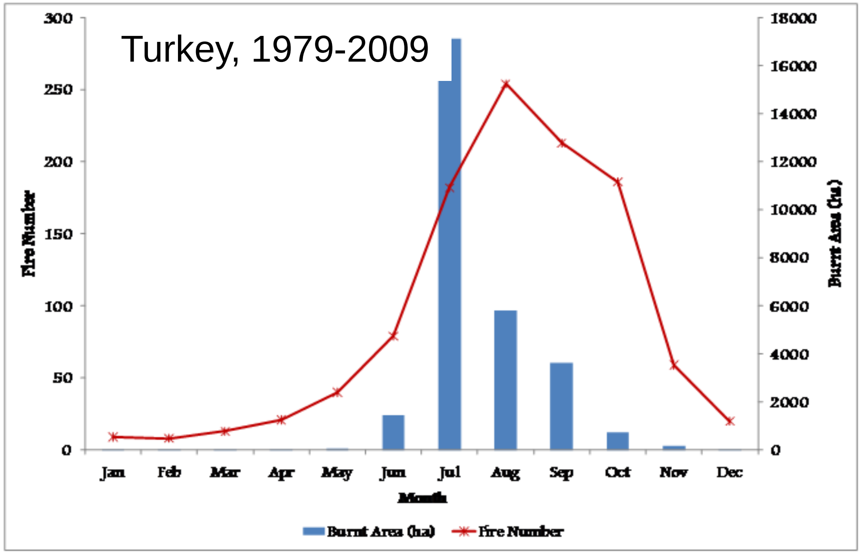
Source: JRC, 2008

Seasonal Variability of Global Vegetation Fires

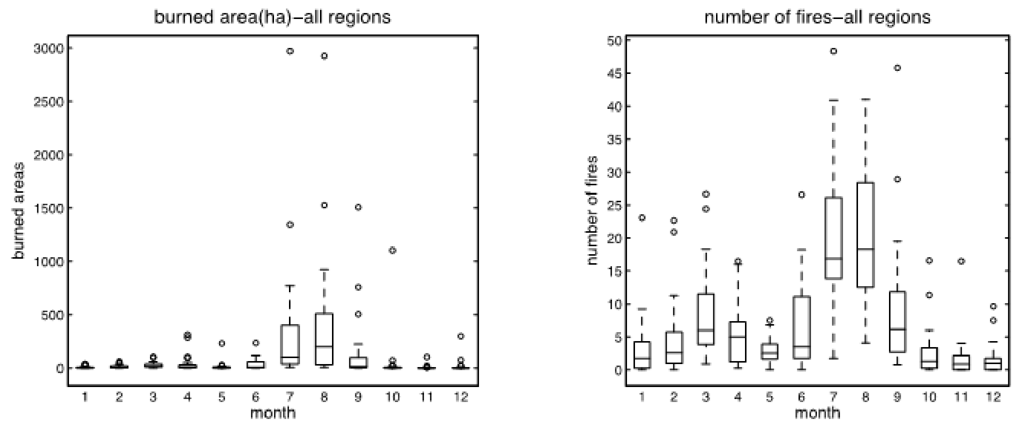




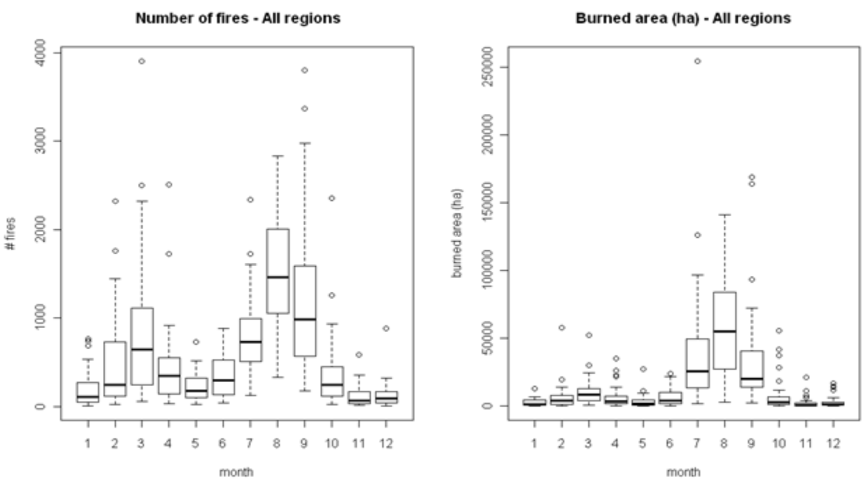
Fire Regime



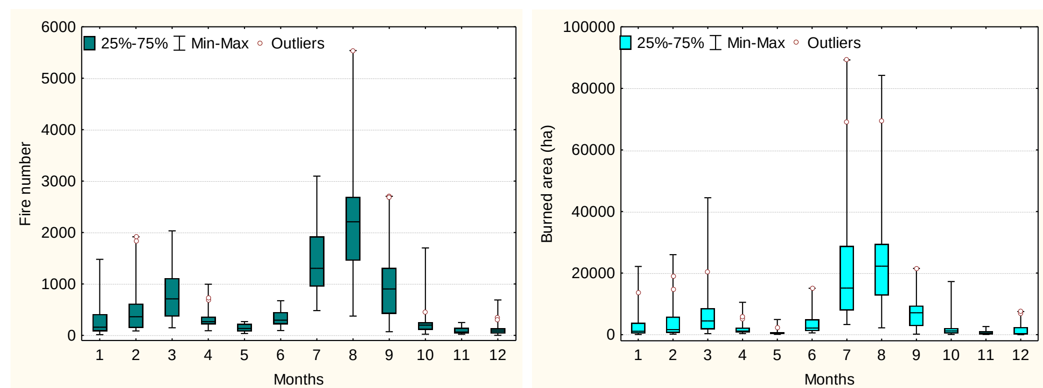
South France, 1981-2006



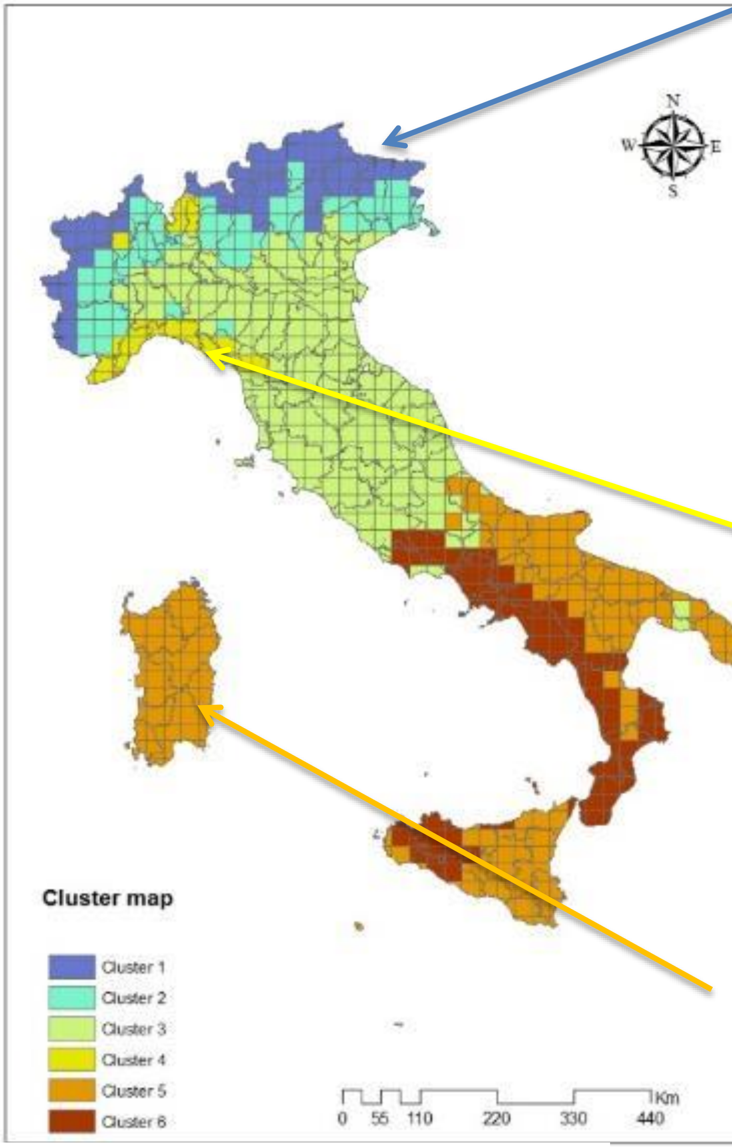
Spain,1974-2008

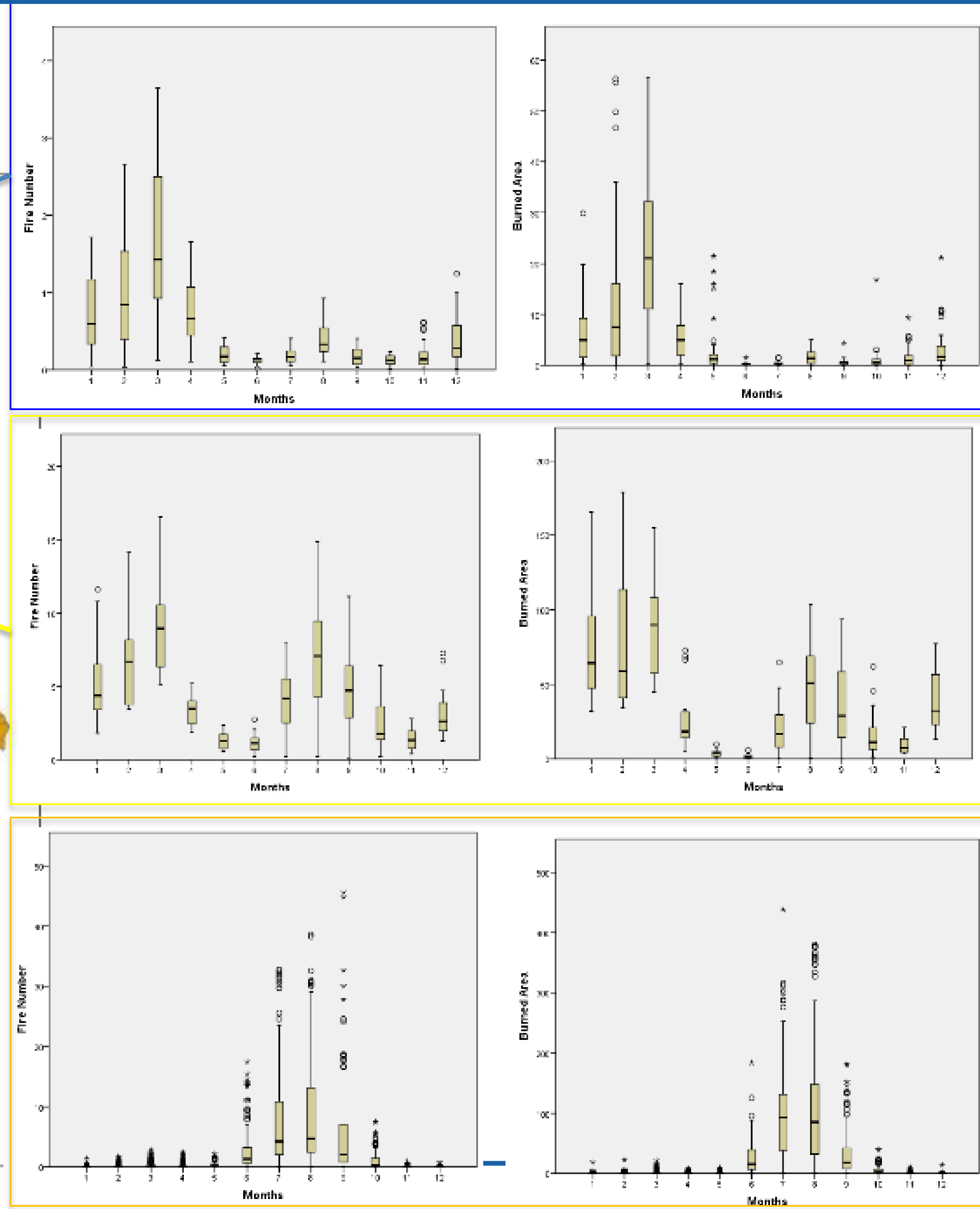


Italy,1985-2008

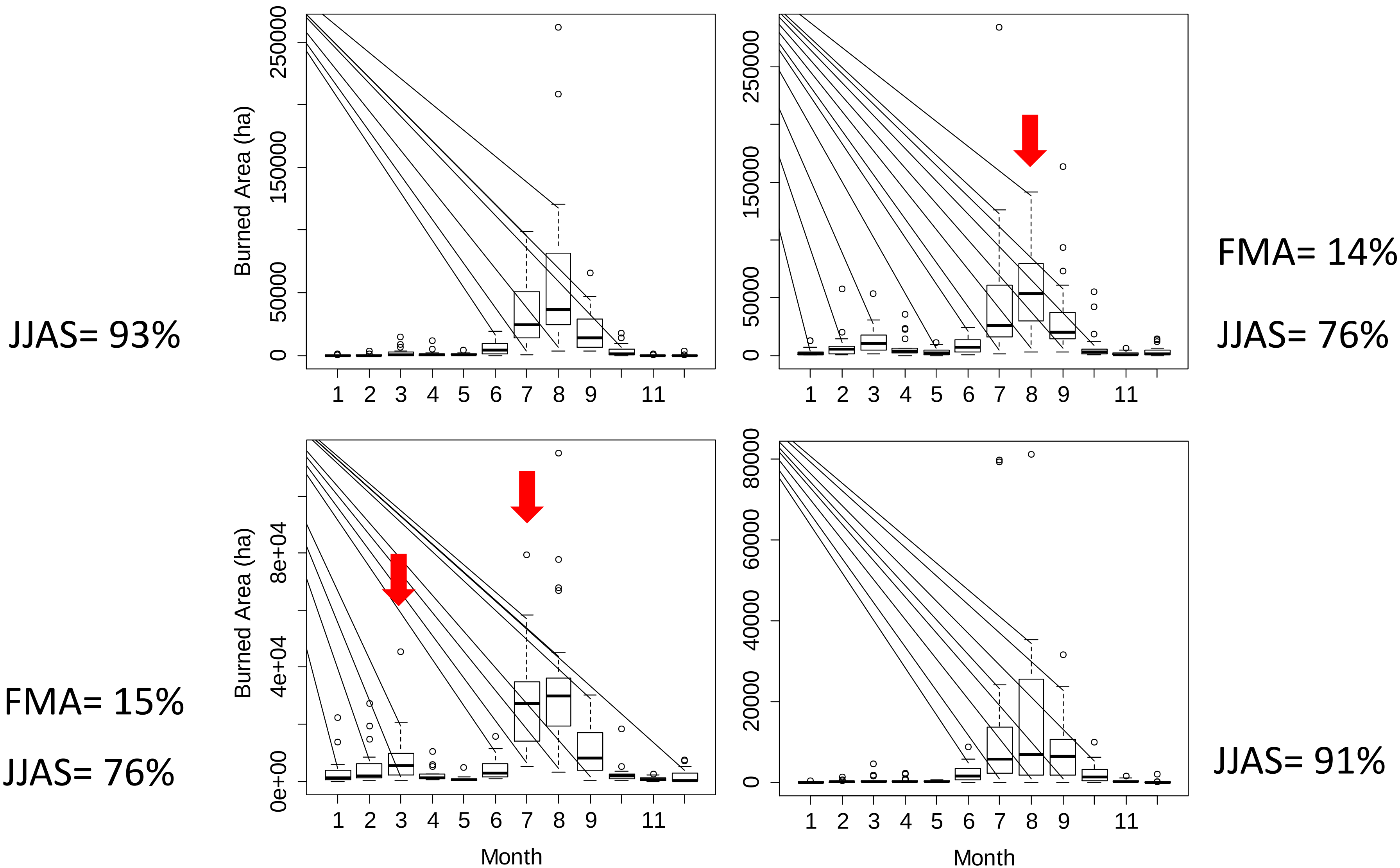


Fire Regime

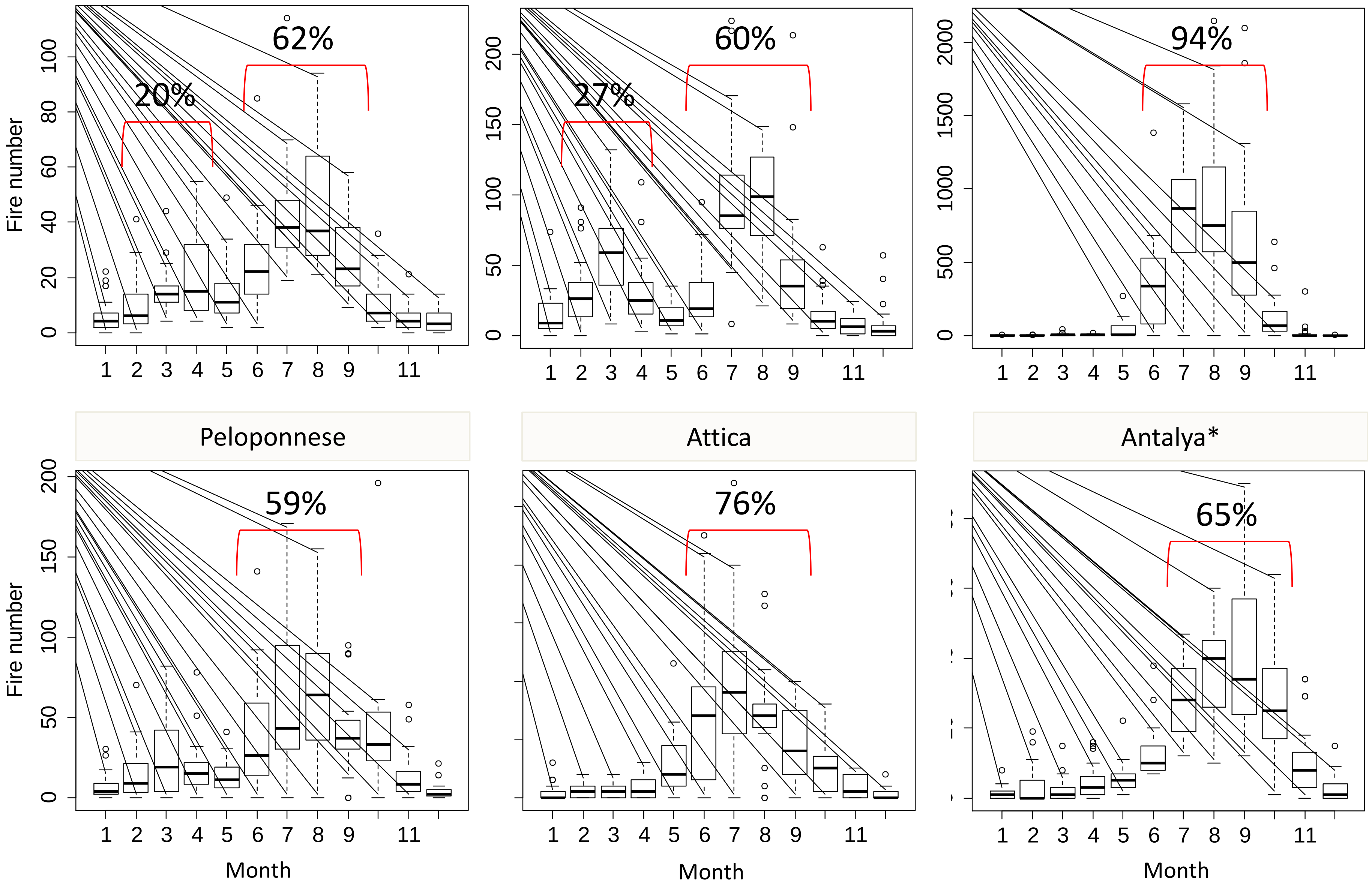




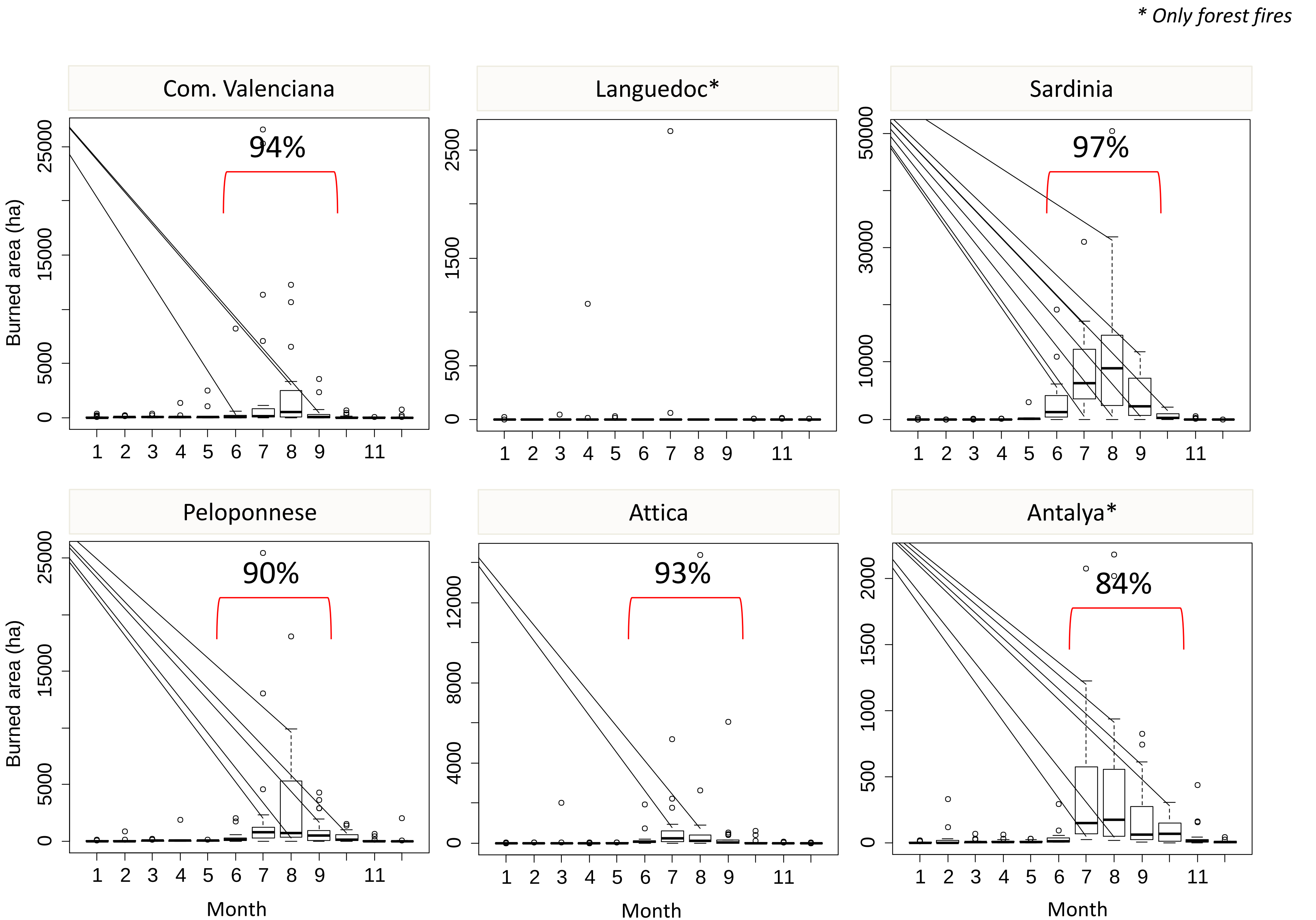
Source: PhD Thesis F. Masala 2012



Burned Area (ha)
250000
150000
50000
0
1 2 3 4 5 6 7 8 9 11
JJAS= 93%
FMA= 14%
JJAS= 76%
8e+04
4e+04
0e+00
80000
60000
40000
20000
Month
FMA= 15%
JJAS= 76%
JJAS= 91%

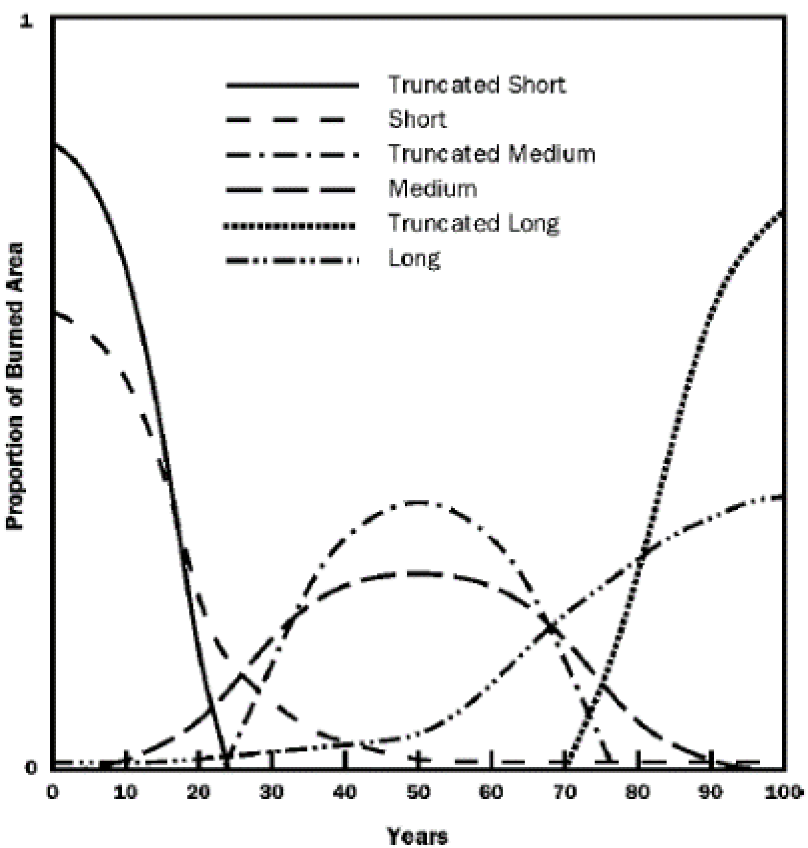


62%
20%
Fire number
Month
60%
27%
94%
Peloponnese
Attica
Antalya*
59%
76%
65%
Fire number
Month
Month
Month


* Only forest fires
Com. Valenciana
Languedoc*
Sardinia
Peloponnese
Attica
Antalya*
94%
97%
90%
93%
84%
Burned area (ha)
Month

Fire Return Interval

Description of *how often* fires occur over several years



Truncated Short Fire-Return Interval - All of the area that burns does so with short fire-return intervals

Short Fire-Return Interval - Most of the area burns at short fire-return intervals

Truncated Medium Fire-Return Interval - The area that burns does so within a range of fire-return intervals that has both upper and lower limits that are defined by the life histories of characteristic species.

Medium Fire-Return Interval - Most of the area burns at medium-return intervals

Truncated Long Fire-Return Interval In all of the burned area, intervals are long (typically greater than 70 years)

Fire Regime

Fire Return Interval

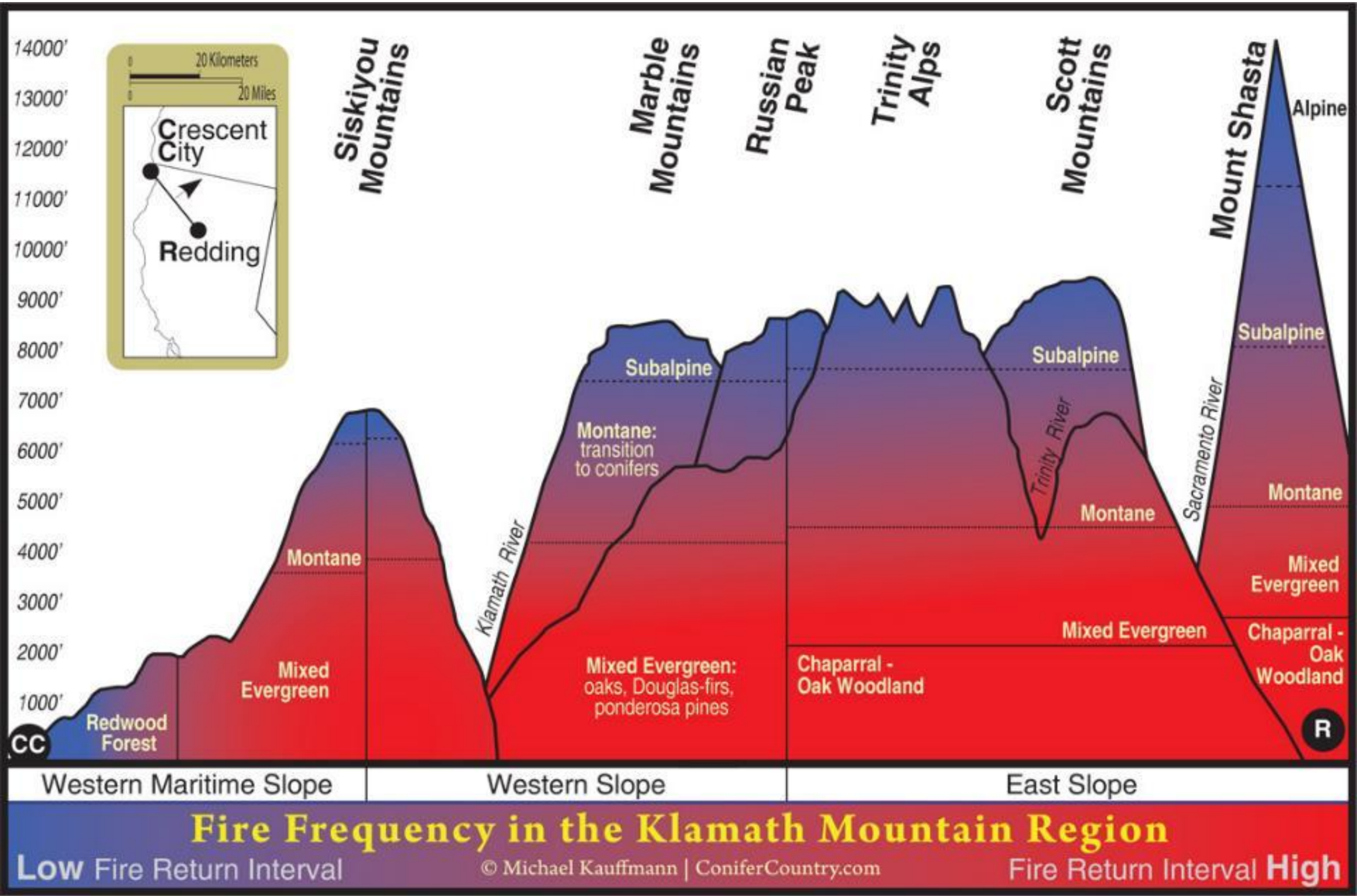
Table 1—Fire regime types[a b]

Fire	Fire-return interval	Fire spread driven by	Fire intensity	Fire effects	Ecosystem examples
	Years				
I	1–35	Surface and other low understory fuels	Heavy understory and fuel consumption	Low to moderate fuel overstory mortality	Ponderosa pine, longleaf, pine oak savanna
II	1–35	Mostly surface fuels	Low to moderate	Aboveground biomass killed, most fuels consumed	Grassland, low scrub
III	35–100	Surface and canopy fuels	Mixed high and low	High understory mortality and fuel consumption, thinning of overstory	Western mixed-conifer, forest Appalachian pine-hardwoods
IV	35–100	Mostly canopy fuels	High	Aboveground biomass killed, high fuel consumption	Chaparral, boreal forest, sagebrush
V	>200	Mostly canopy fuels	High	Aboveground biomass killed, high fuel consumption	Lodgepole pine forest, subalpine forest, Eastern U.S. deciduous forest

[a] These are modal groups from a continuum of patterns seen in nature. See Kilgore (1987) for summary review of fire regime literature.
[b] Source: Modified from Schmidt et al. 2002.

Fire Regime

Fire Return Interval

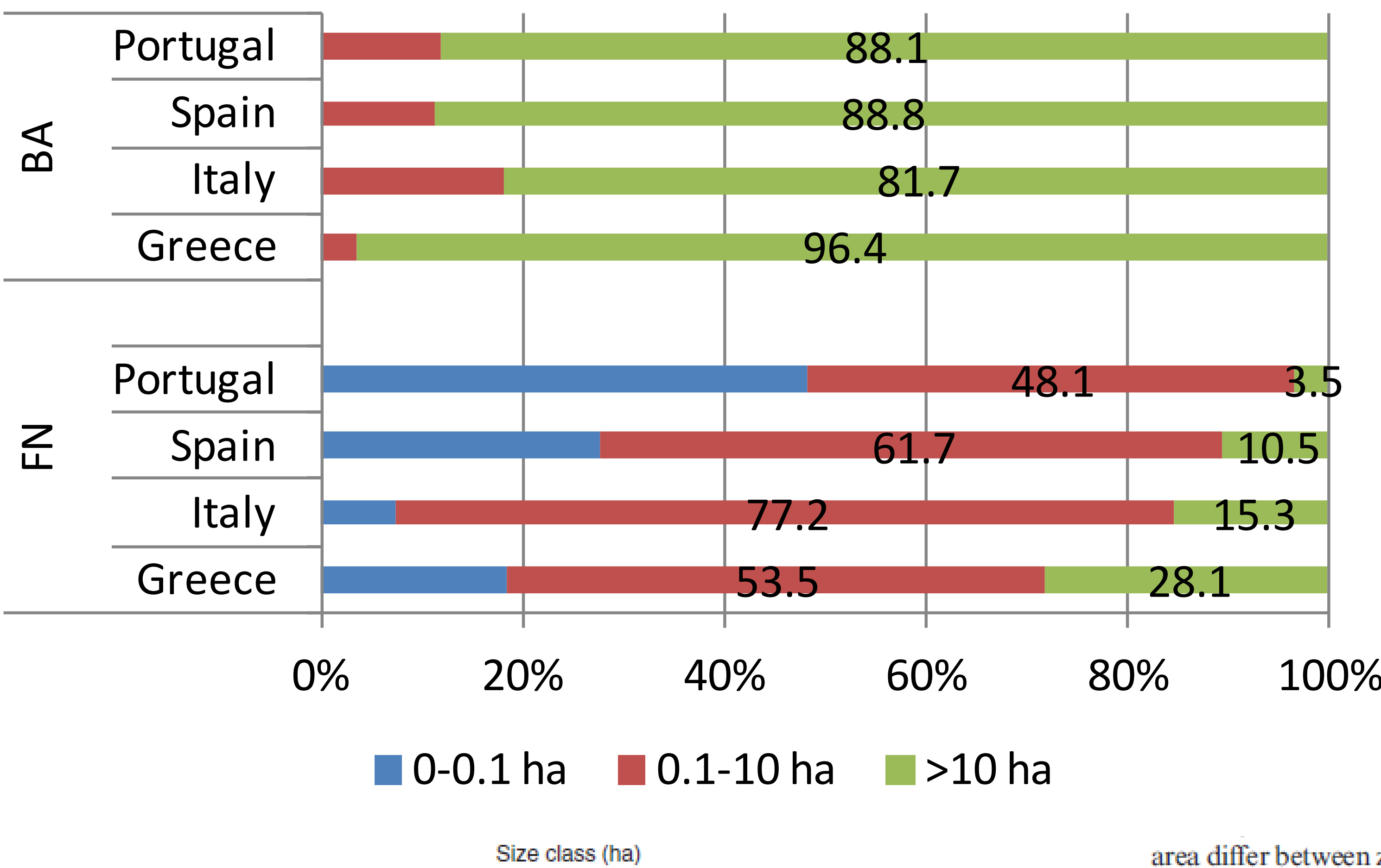


Characteristic distribution of area within the fire perimeter

CLASS	SIZE
Small Fire Size	Most of the area that burns does so in fires **smaller than 10 ha** with larger fires accounting for much less of the total area burned
Truncated Small Fire Size	All of the burned area is in small fires, usually **less than 1 ha**
Medium Fire Size	Most of the area that burns does so in medium-sized fires that range from **10 to 1,000 ha**
Large Fire Size	Most of the area that burns is in large fires that are **greater than 1,000** ha in size with smaller fires accounting for a lower proportion

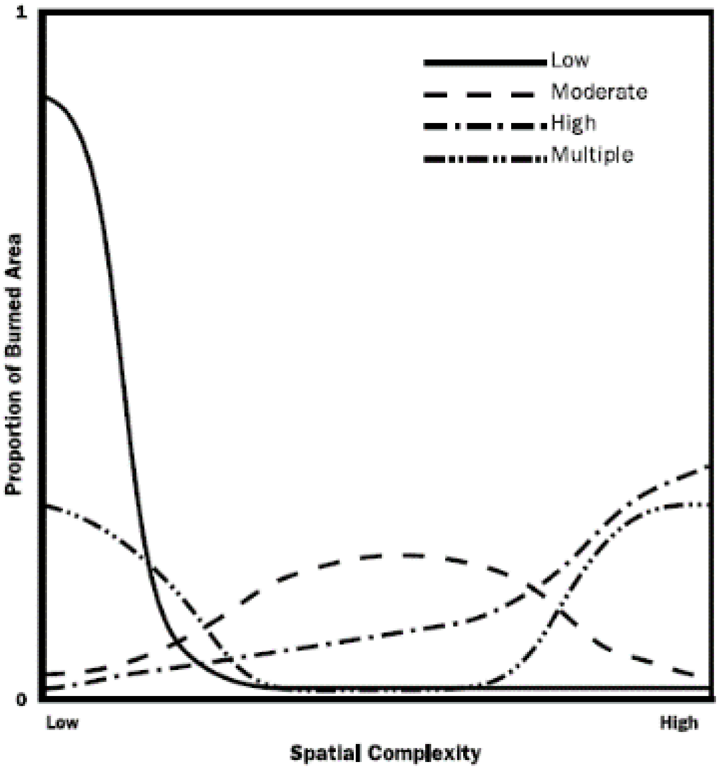
Fire Regime

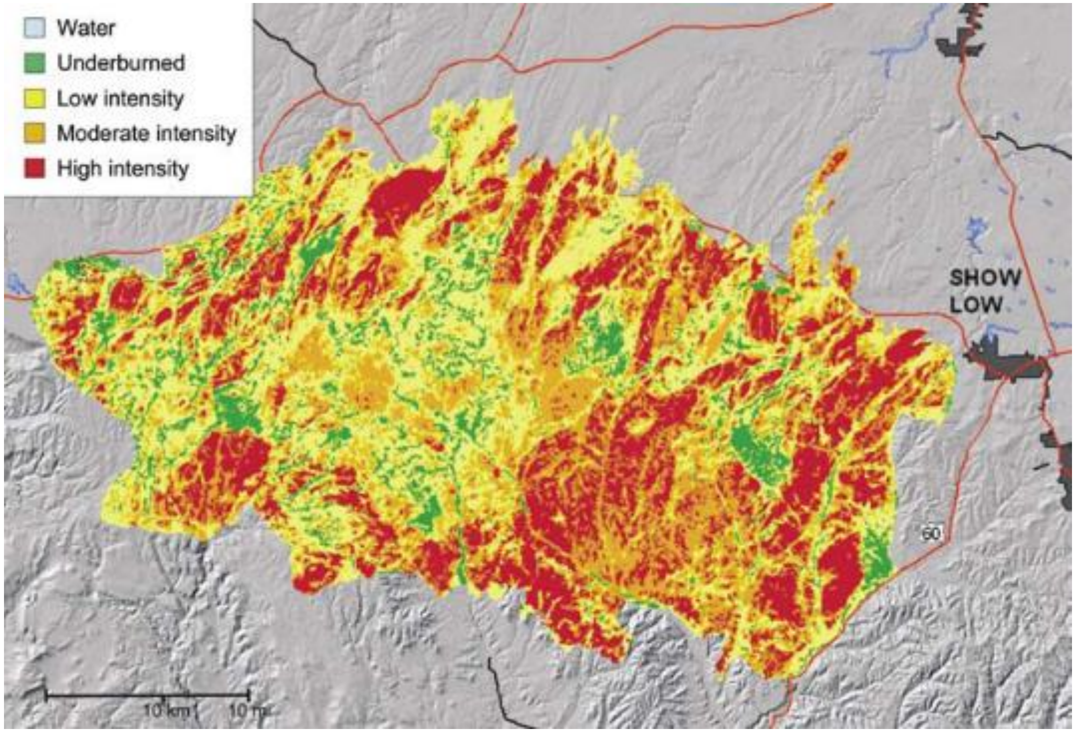
Fire Size



vegetation burnt i
tween 1970 and 200
n the fynbos biome
per of fires in each siz
. Note that scales fo
area differ between zones.

Spatial complexity, or patchiness, is the spatial variability in fire severity within the fire perimeter.

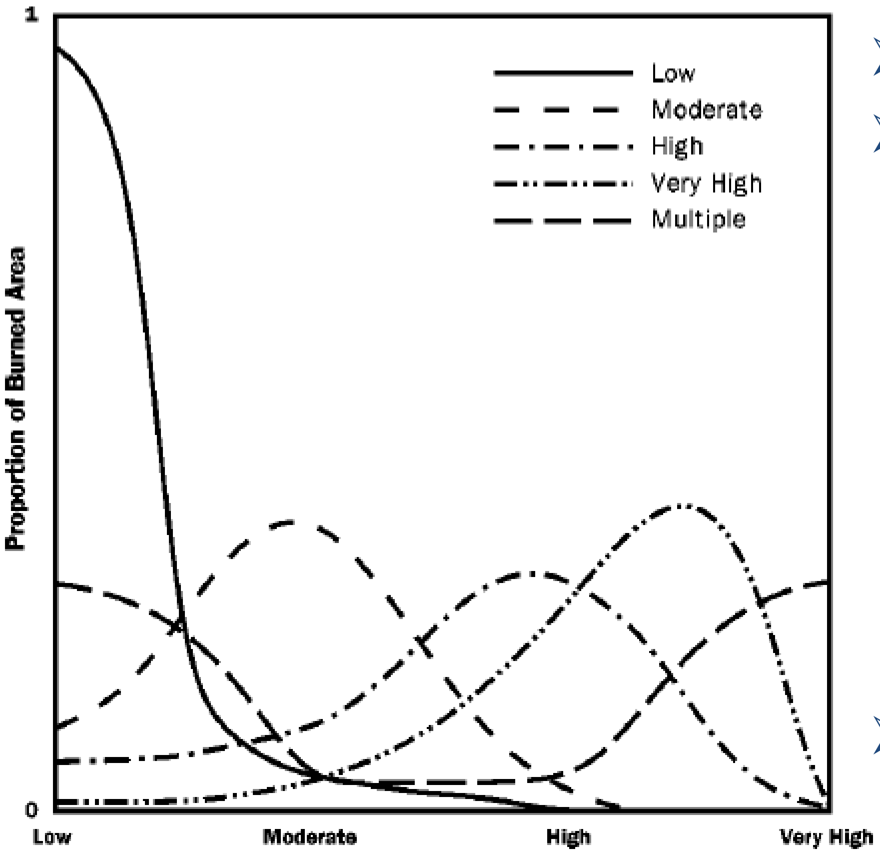




Mosaic fire pattern mapped for the Rodeo-Chedeski Fire, Arizona

Fire severity

Magnitude of the effect that fire has on the environment

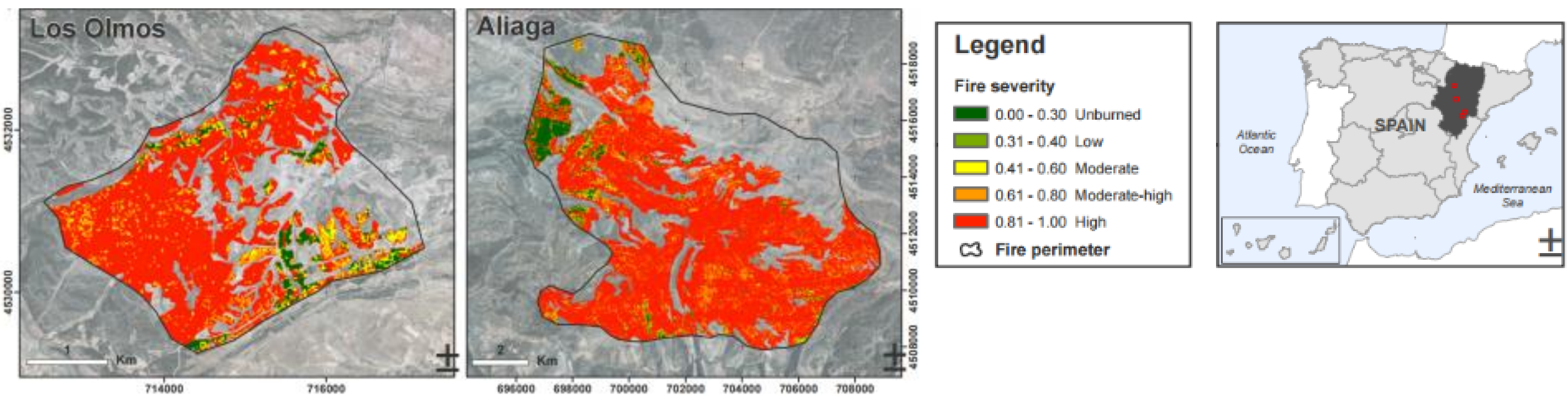


- Effect of fire on the ecosystem
- Some measures of severity…
  - % of organic biomass consumed by fire
  - % soil organic matter consumed
  - Mortality of plants and animals
  - Depth of heat penetration into the soil
  - Change in color of ash and soil
  - Description of fire behavior (surface, ground, crown)
- Most common measure of severity
  - Mortality in overstory vegetation

Fire Regime

Fire severity

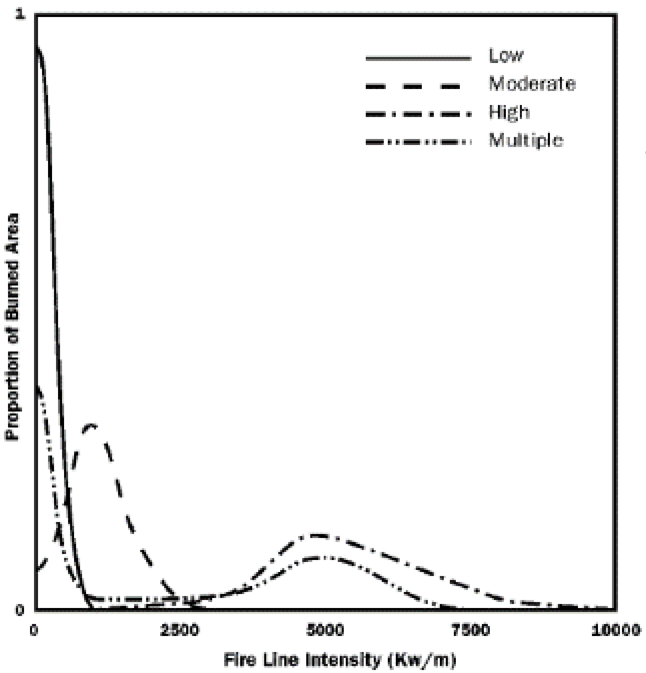
FIRE SEVERITY
Magnitude of the effect that fire has on the environment



Source: Montealegre et al., 2014

Fire intensity

Fireline intensity is a measure of energy release per unit length of fire line



CLASS	Fireline Intensity (kW m^{-1})	Flame lenght (m)	Ecosystems
Low Fireline Intensity	<346	<1,2	Grassland
Moderate Fireline Intensity	346 - 1.730	1,2 - 2,4	Conifers
High Fireline Intensity	>1730	>2,4	Pinus stand and mediterranean maquis
Multiple Fireline Intensity	Low in surface fires; high in crown fires		Conifers

Biogeographical Patterns of Fire Regimes

Table 1—Fire regime types[a] [b]

Fire	Fire-return interval	Fire spread driven by	Fire intensity	Fire effects	Ecosystem examples
	Years				
I	1–35	Surface and other low understory fuels	Heavy understory and fuel consumption	Low to moderate fuel overstory mortality	Ponderosa pine, longleaf, pine oak savanna
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[a] These are modal groups from a continuum of patterns seen in nature. See Kilgore (1987) for summary review of fire regime literature.
[b] Source: Modified from Schmidt et al. 2002.



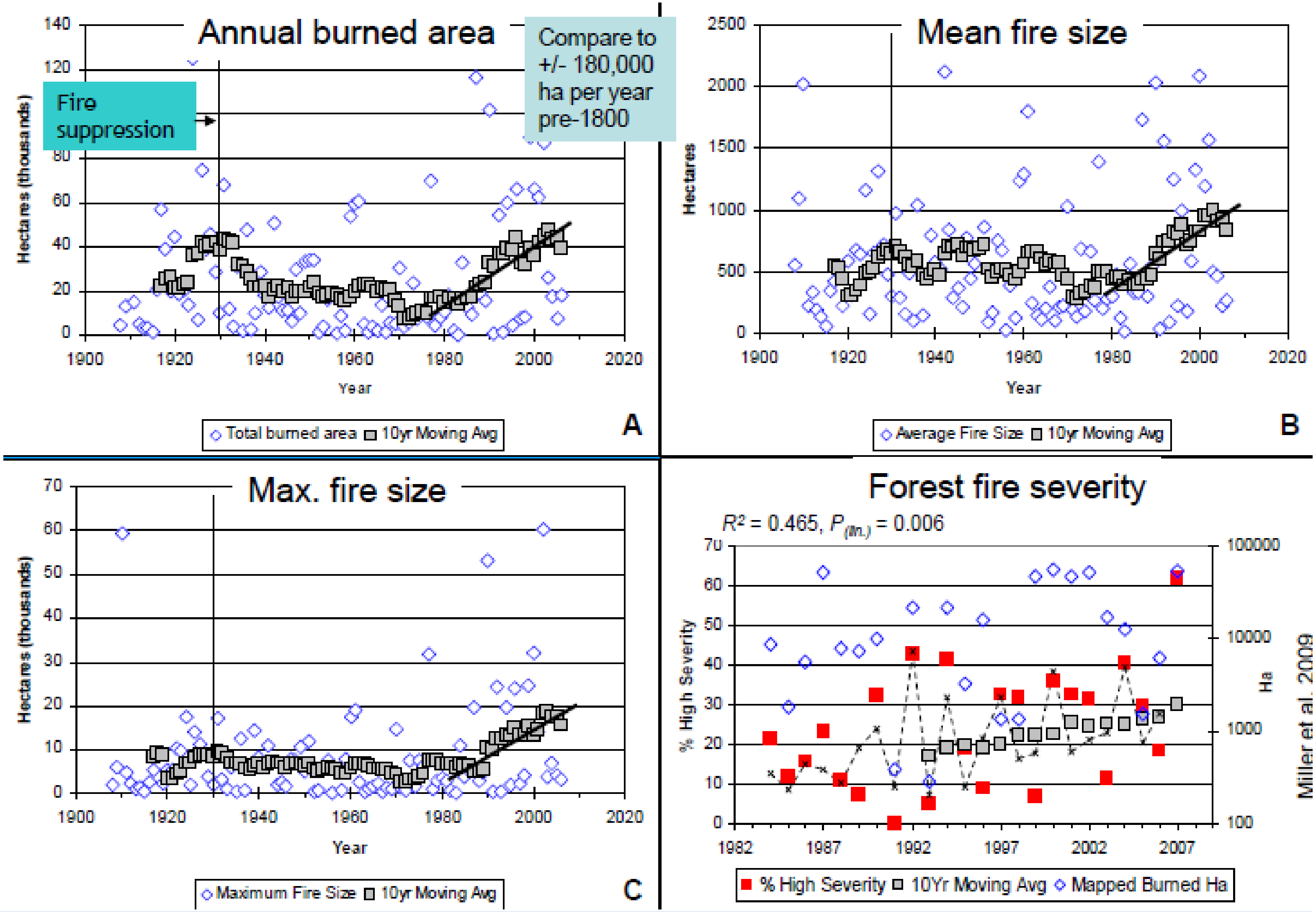

Biogeographical Patterns of Fire Regimes

Biome	Fire frequency	Fire season	Intensity	Severity
Grassland	Annual or more (depends on grazing pressure and rainfall)	Dry season, while grasses are dormant	Low-moderate	Surface
Chaparral	25-100 years	Dry summer periods	Very high	Crown
African savannas	1-30 years (depending on annual rainfall)	Dry summer periods	Low-moderate	Surface
Brazillian Cerrado	1-3 years	Dry winters	Low-moderate	Surface
North American conifer forests	Frequent (1-10 year) surface, 100-1000 year crown	Dry summers	Low surface, very high crown	Surface or crown
South American rain forests	Very infrequent (possibly restricted to one tree)	Only after several rainless days	Very low	Surface

Fire Regime

Examples

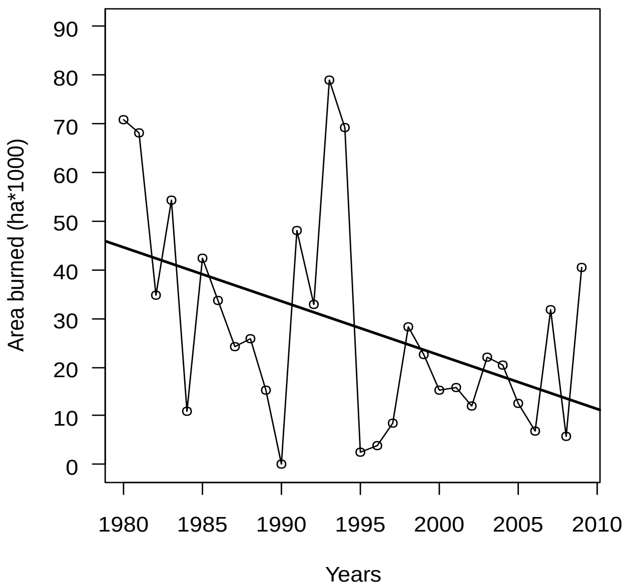
Sierra Nevada: trends in fire area and severity

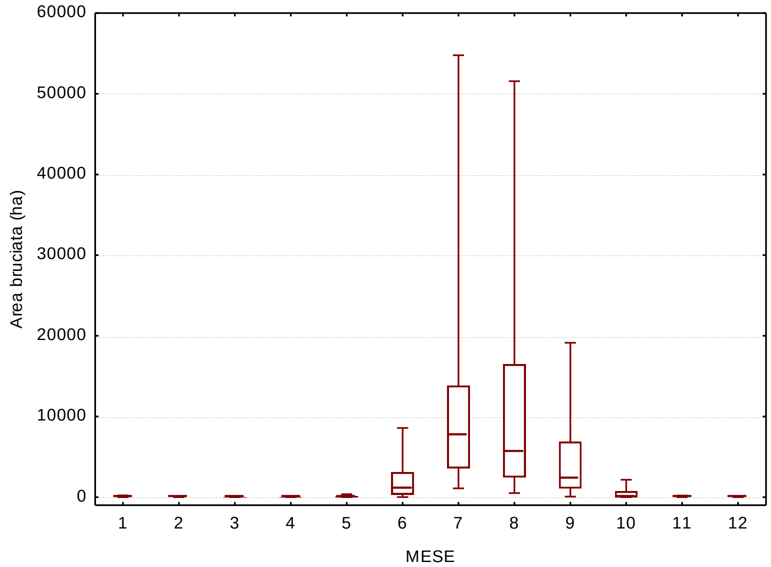


source: Miller et al., 2009

Fire Regime

Examples – Sardinia 1980-2010





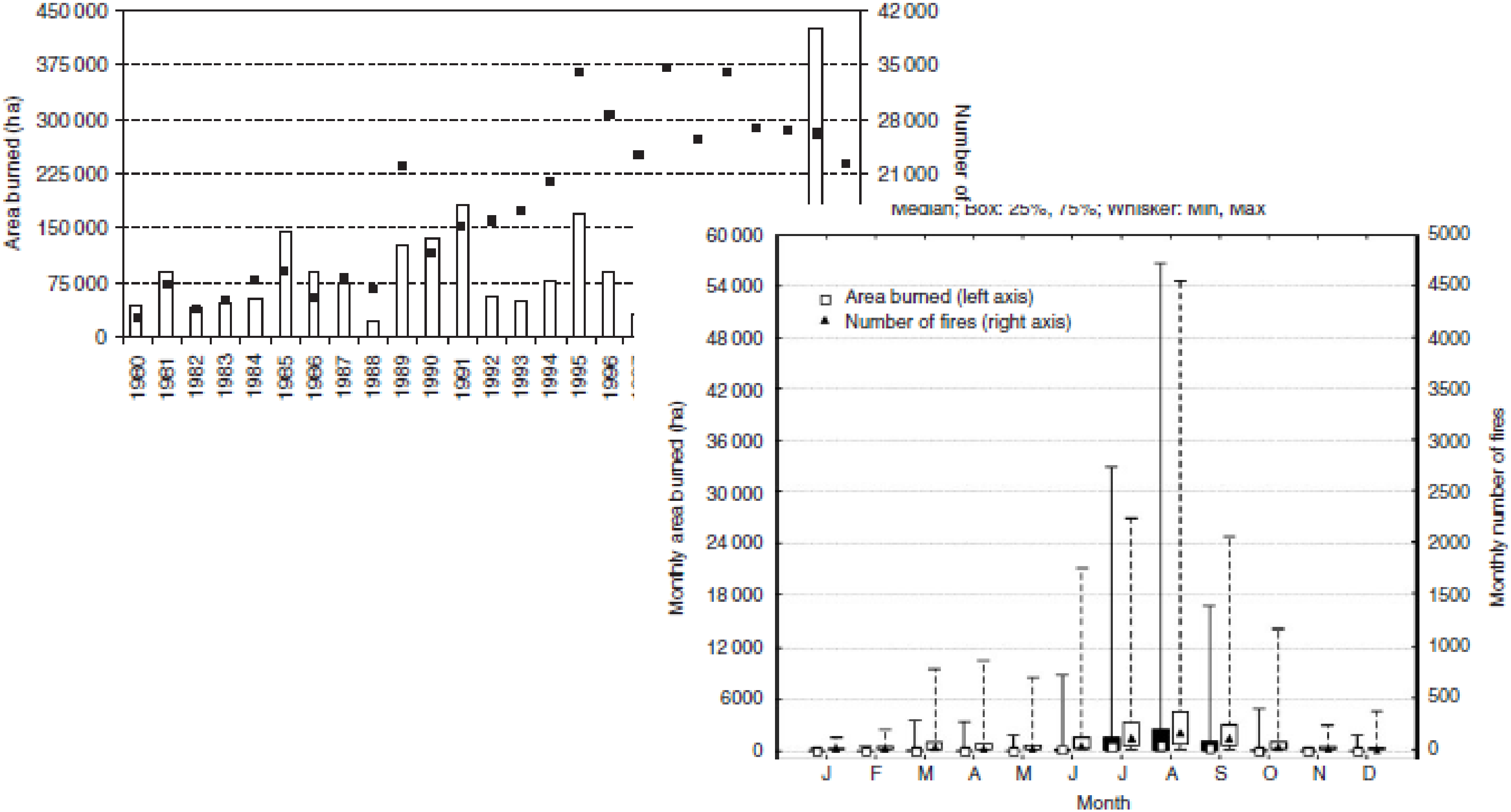
BA

Luglio (37%)
Agosto (40%)
Settembre (14%)
Giugno (7%)

source: Bacciu et al., 2012 in preparation

Examples – Portugal 1990-2004

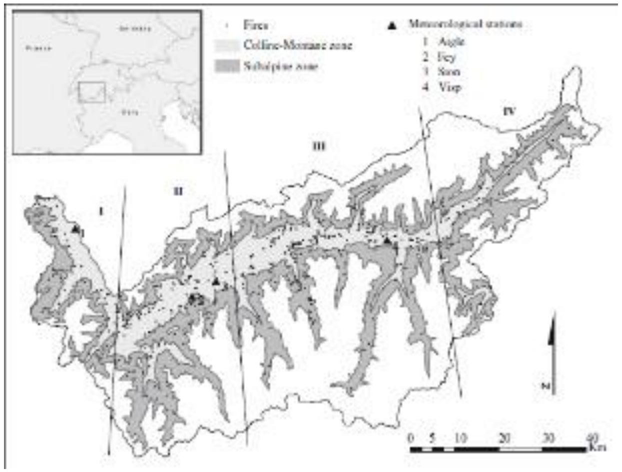
Portugal, 1980-2004

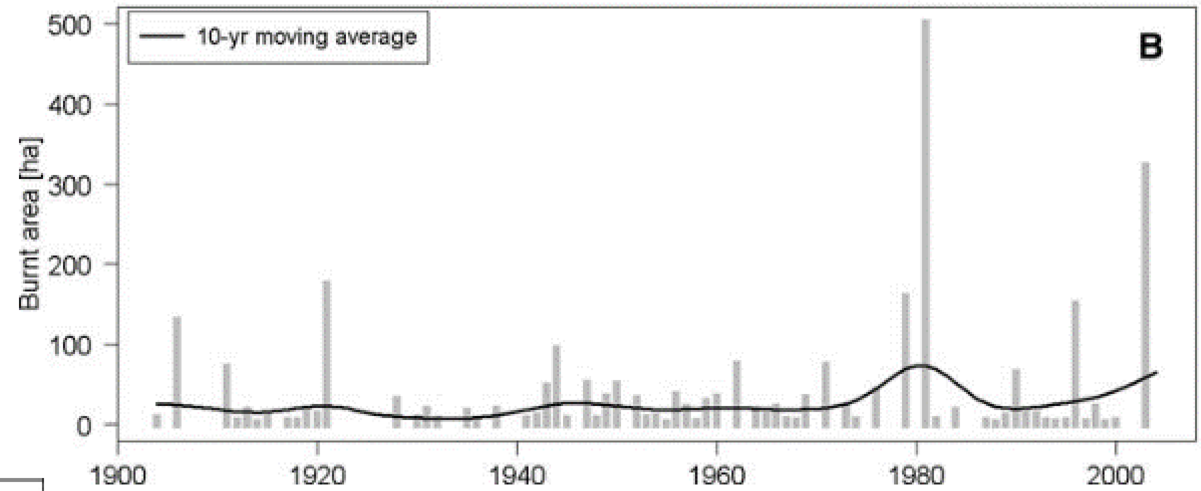


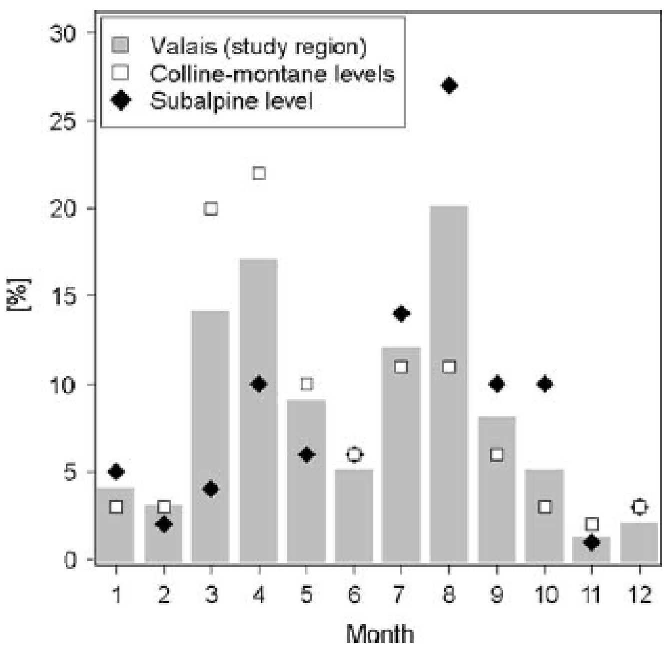
source: Carvalho et al. 2008

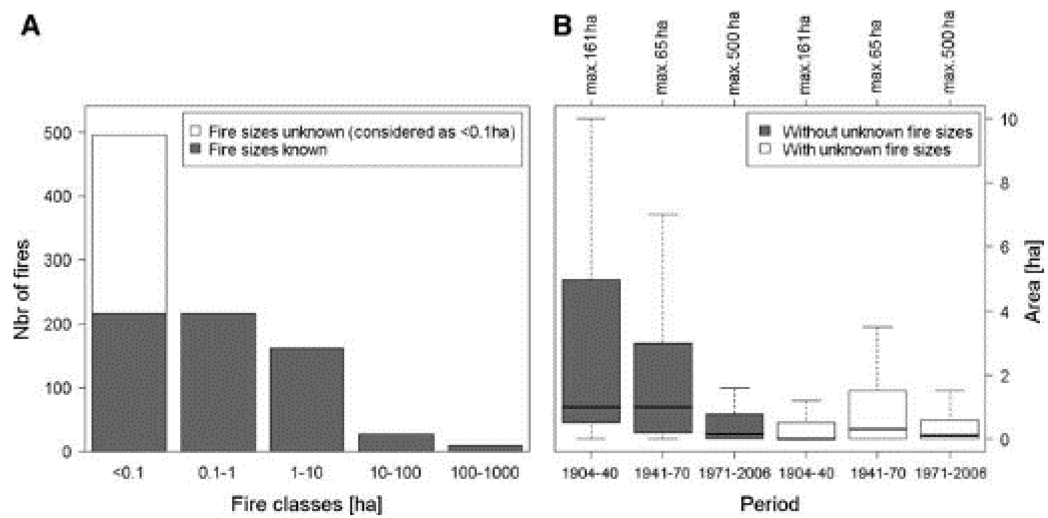
Fire Regime

Examples – Switzerland 1904-2006









Zumbrunnen et al., 2009

Fire Regime

Examples – South Africa 1970-2007

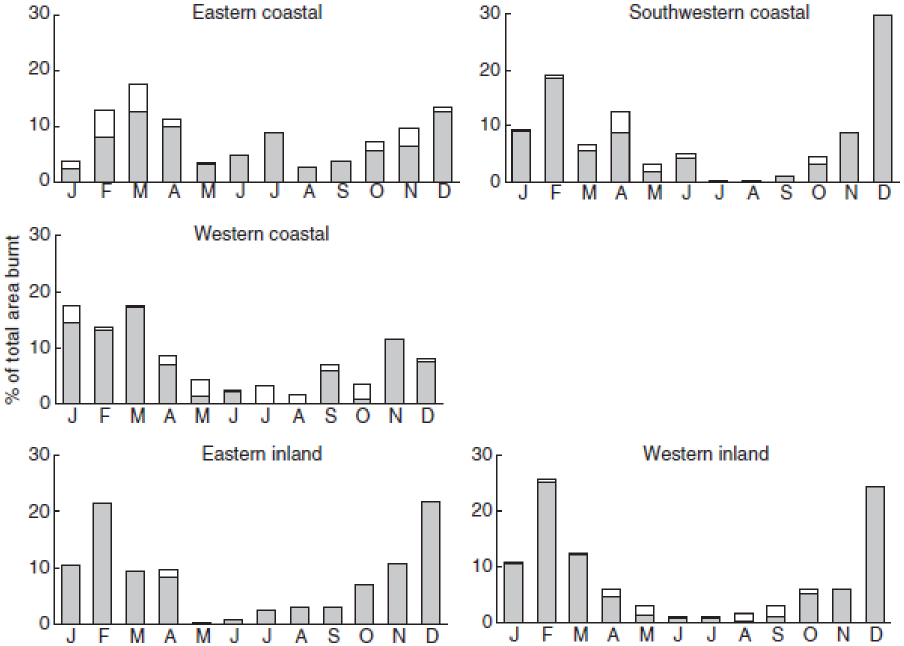


Fig. 2. Proportion of fynbos vegetation burnt in each month between 1970 and 2007 in five climate zones in the fynbos biome, South Africa. Un-shaded portions denote prescribed burns and shaded portions denote all other fires.

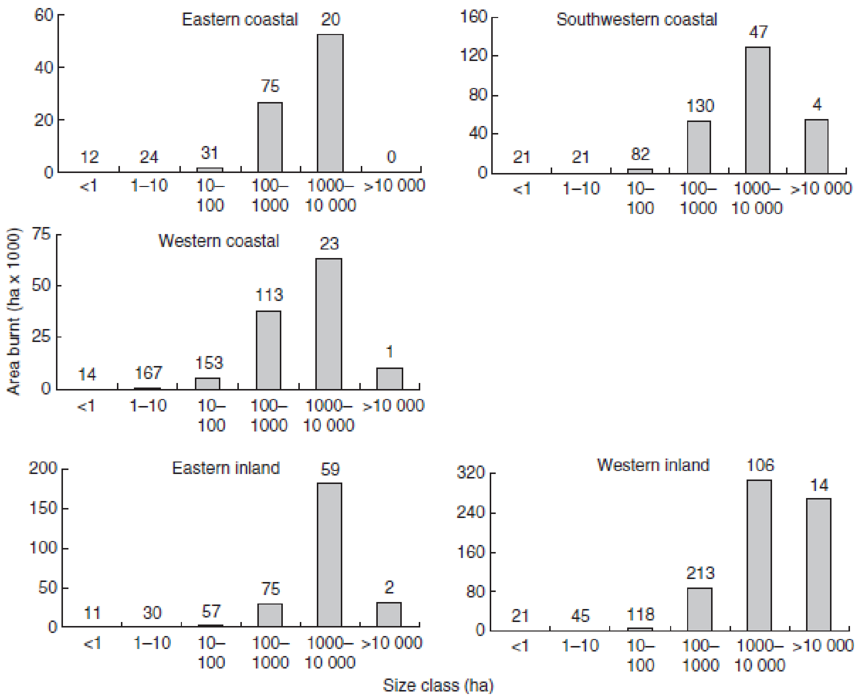


Fig. 3. Area of fynbos vegetation burnt in fires of different size between 1970 and 2007 in five climate zones in the fynbos biome, South Africa. The number of fires in each size class is given above bars. Note that scales for area differ between zones.

4. L'interaction avec les facteurs météorologiques et climatiques

Centro Euro-Mediterraneo sui Cambiamenti Climatici

Fire & Biosphere: a complex interaction

Fire regime is considered to be governed by:

Climate and Weather

Fuels (vegetation characteristics)

Topography

Socio-Economics

In several areas of the world, weather and climate were found to be the most important factors influencing fires

Fire and weather relationships

Fire occurrence in the Mediterranean region varies considerably from year to year, suggesting a strong dependence on meteorological conditions. In fact, climate and weather are two key fire drivers acting directly and indirectly.

Weather acts as a **predisposing agent**, and rapid changes in relative humidity, temperature, and wind speed and direction may dramatically influence fire behaviour.

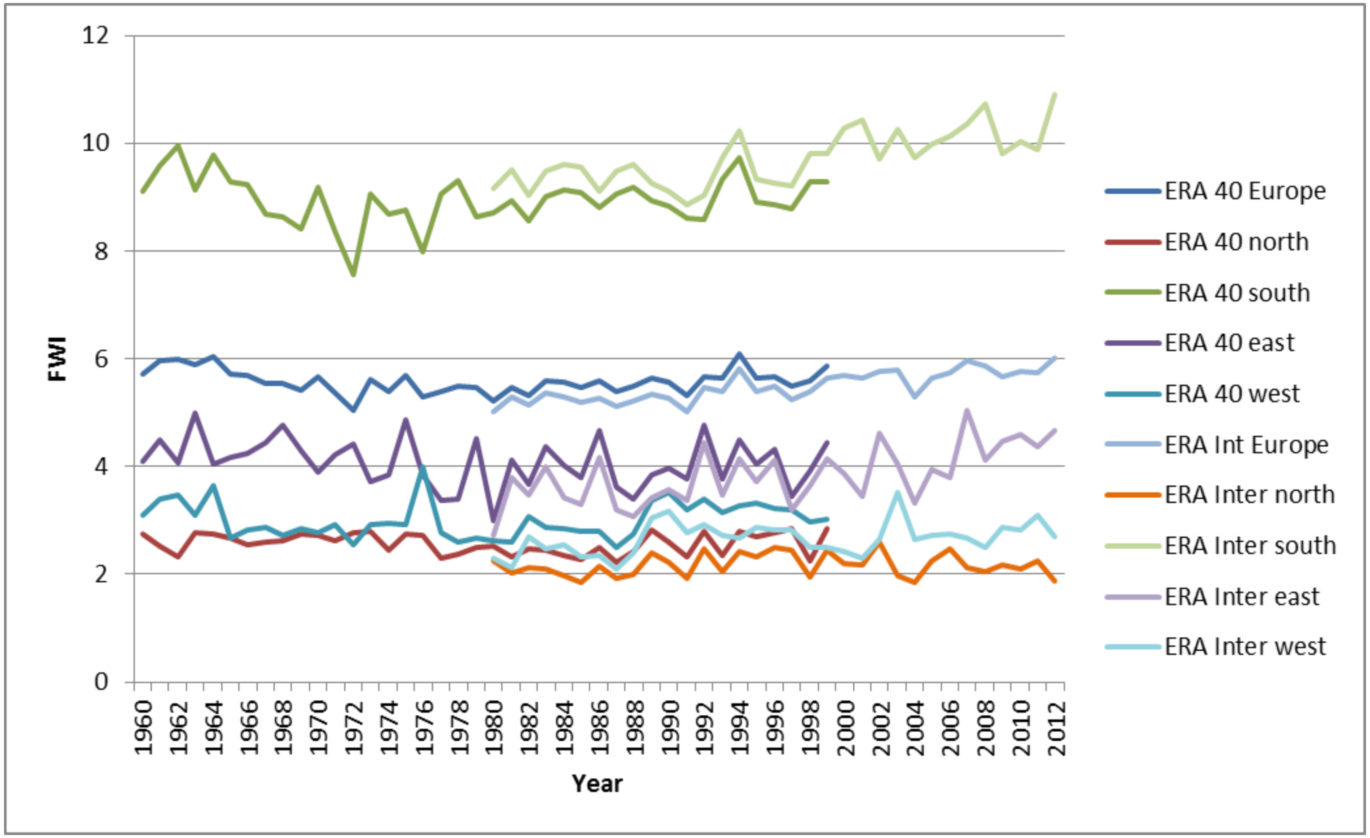
Weather may influence changes in fuel flammability and fuel moisture content (Chuvieco et al., 2004; Pellizzaro et al., 2007b; Cardil et al., 2013), or directly ignite fires through lightning (Vázquez and Moreno, 1993), or modulate fire spread through wind (Butler et al., 2006a; Arca et al., 2007; Forthofer et al., 2011).

Climate influences fuel type distributions, vegetation productivity and fuel accumulation (Renkin and Despain, 1992; Pyne et al., 1996; Kunkel, 2001; Carvalho et al., 2008).

“Temporal variation of forest fire danger in Europe in 1960-2012”

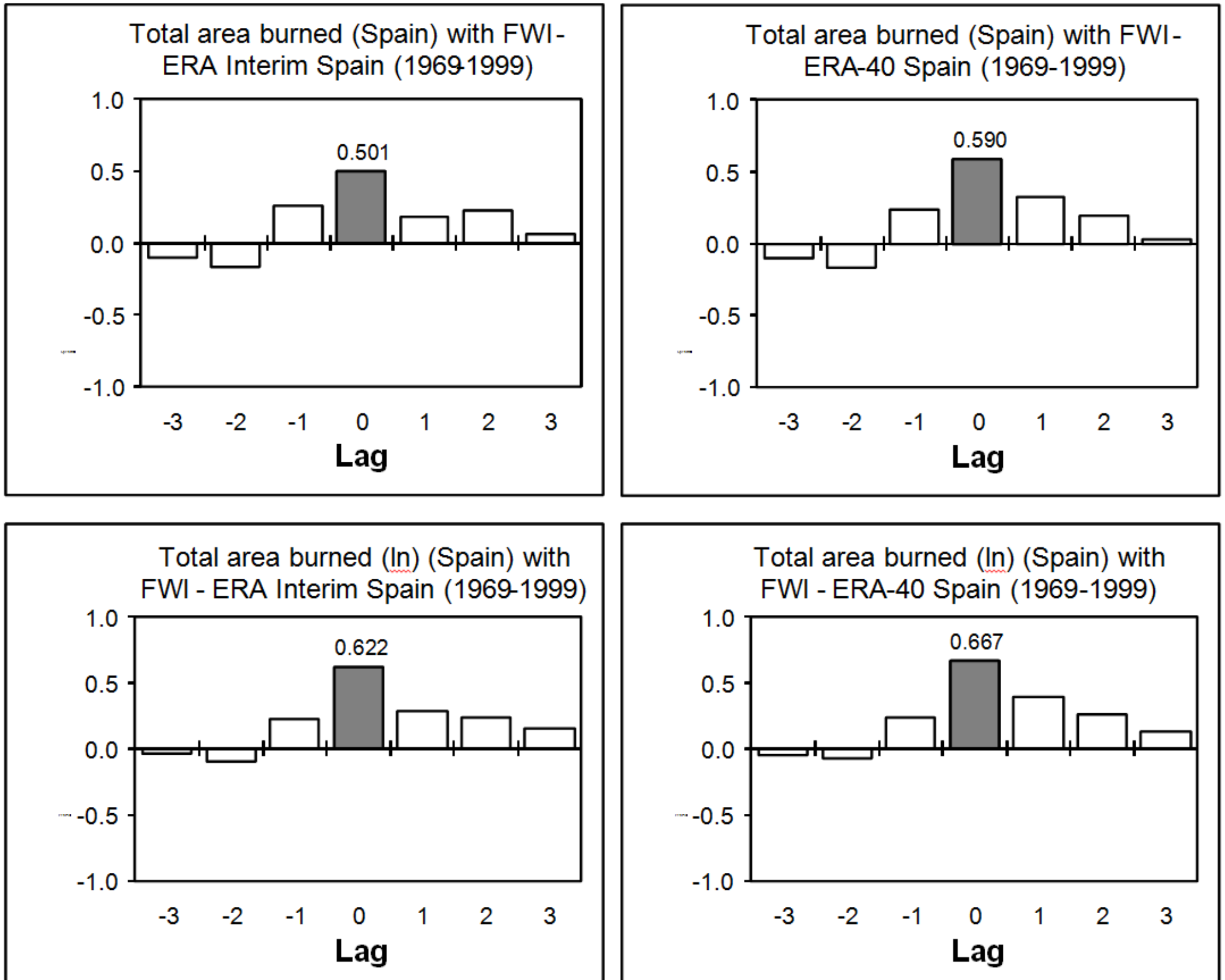
The year-to-year variation of March-September mean FWI from ERA 40 and ERA Interim datasets for four selected areas and for the whole of Europe.

Increased fire danger in southern and eastern Europe after around 1980



Venäläinen et al 2013

“Temporal variation of forest fire danger in Europe in 1960-2012”



Cross-correlation graphs between total burned area (original and ln transormed) at national scale in Spain and FWI values estimated from ERA south and ERA Interim south data for the period 1969-1999 (gray columns indicate significant values at 95% confidence level).

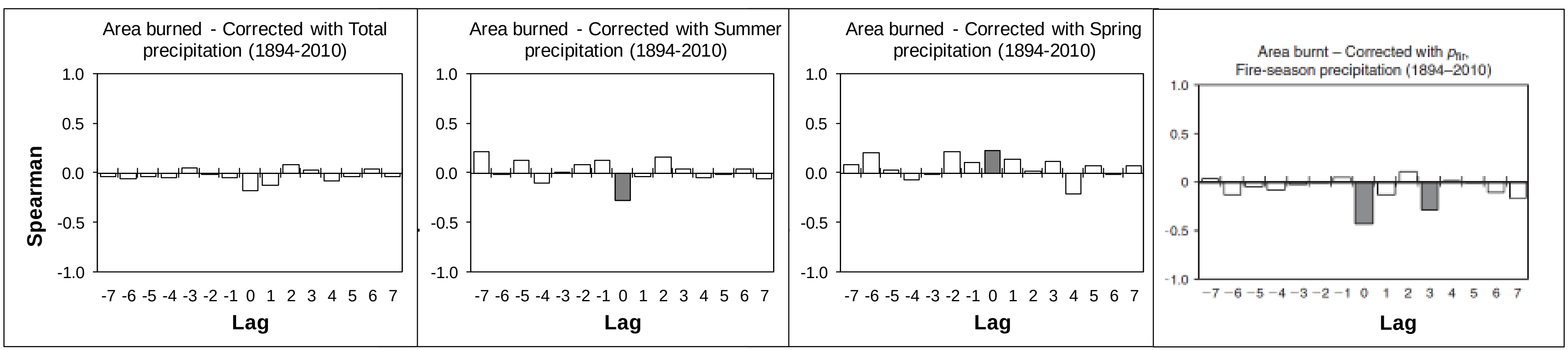
Venäläinen et al 2013

“On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010)”

Spearman's Correlation	1894-2010	
	Number of fires	Area burned
Mean temperature	.405**	.225*
Mean minimum temperature	.406**	0.186
Abs minimum temperature	.227*	0.201
Mean maximum temperature	.657**	.442**
Abs maximum temperature	.501**	.451**
Total precipitation	-0.008	-0.181
Winter precipitation	-0.074	-0.174
Spring precipitation	0.18	.227*
Summer precipitation	-0.206	-.281*
Autumn precipitation	-0.013	-0.16
Fire-season precipitation	-0.178	-.385**

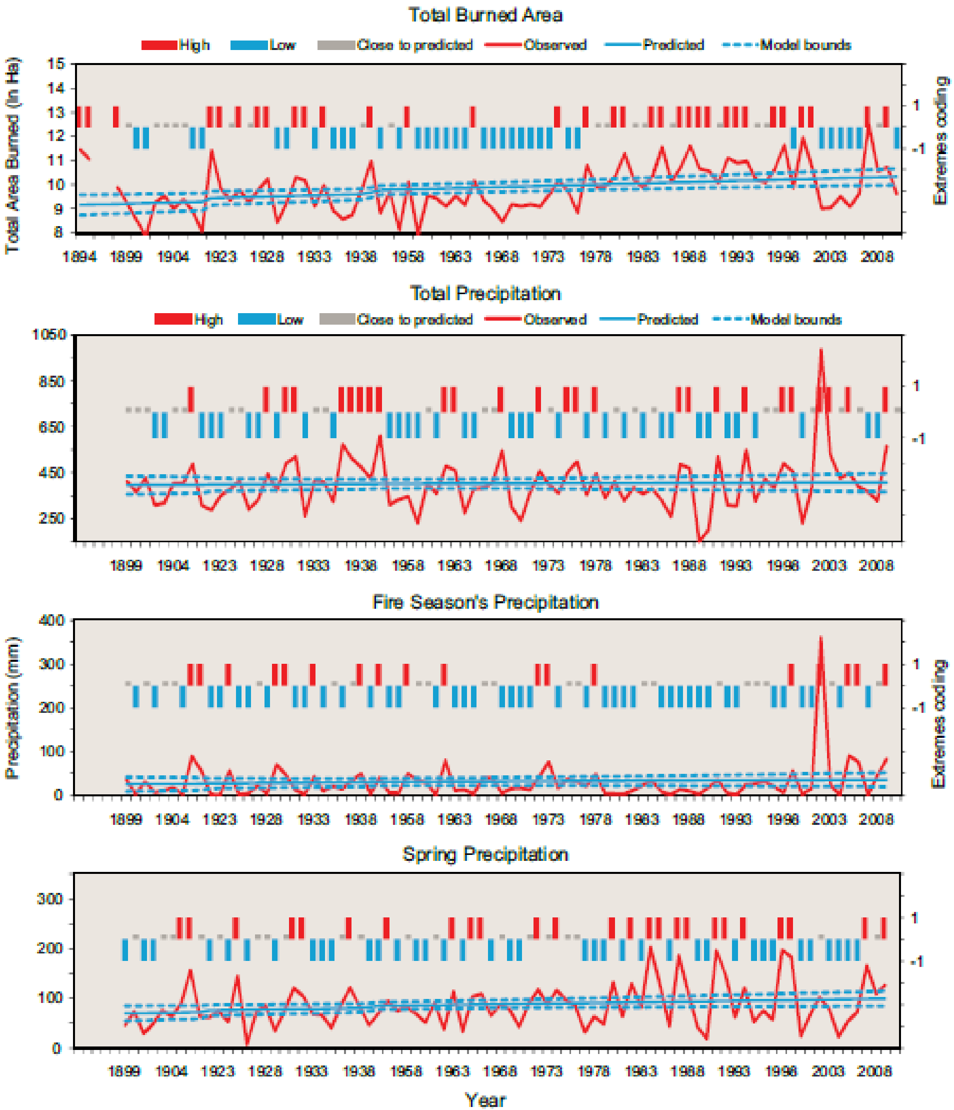
Strong correlation of area burned with abs maximum air temperature (positive), fire-season precipitation (negative) and spring precipitation (positive). Similar outputs for number of fires.

The dual role of precipitation in fuel build-up and dryness



Koutsias et al., 2013

“Precipitation dominates fire occurrence in Greece (1900–2010): its dual role in fuel build-up and dryness”



The dual role of precipitation in fuel build-up and dryness

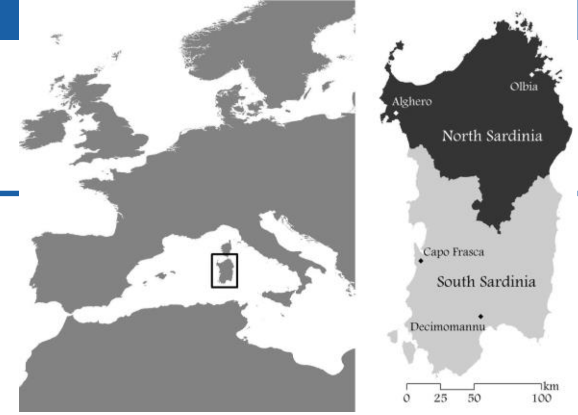
Concerning the meteorological parameters, fire season precipitation is the dominant factor coinciding with area burned.

		Total Area Burned			
		-1	0	1	Sum
Spring Precip.	-1	17(11-19)	9(4-11)	11(10-18)	37
	0	11(4-12)	4(1-7)	4(4-10)	19
	1	6 (7-14)	4(2-9)	15(6-13)	25
	Sum	34	17	30	81

		Total Area Burned			
		-1	0	1	Sum
Fire Season Prec	-1	11(14-22)	7(6-13)	25(12-20)	43
	0	10(5-12)	7(1-7)	3(4-11)	20
	1	13(4-11)	3(1-7)	2(3-10)	18
	Sum	34	17	30	81

Xystrakis et al., 2013

“Large wildland fires and extreme temperatures in Sardinia (Italy)”



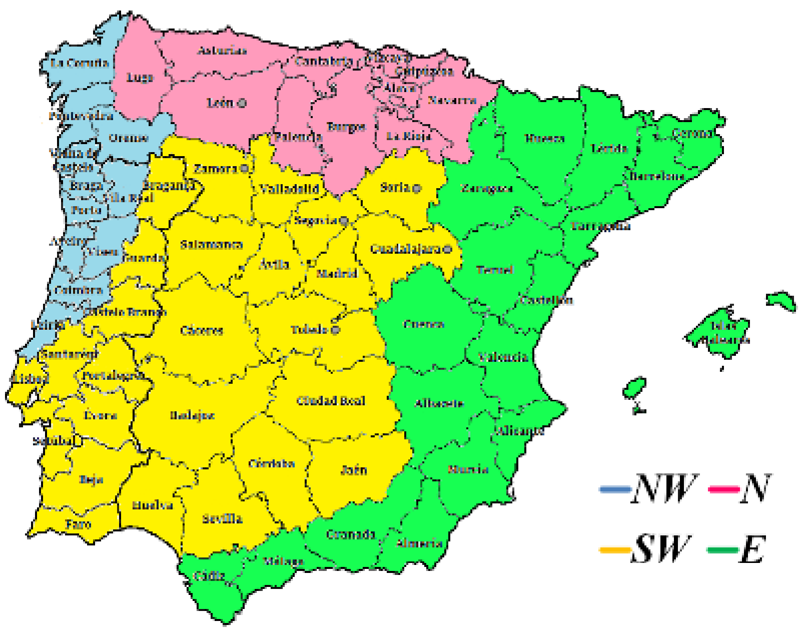
Tab. 4 - Summary of the relationship between large wildland fires (LWF) classes and days classified as high temperature days (HTD) or non-HTD, in the northern and southern part of Sardinia, from 1991 to 2009.

Kind	Description	North			South		
		LWF_{100}	LWF_{500}	LWF_{1000}	LWF_{100}	LWF_{500}	LWF_{1000}
HTD	Number of days classified as HTD		36			72	
	HTD with LWF (%)	41.6	22.2	11.1	30.6	11.1	2.8
	Normalized LWF average number per HTD with LWF	2.7 ± 0.69	2.1 ± 0.65	2.2 ± 0.75	1.6 ± 0.21	1.2 ± 0.21	0.8 ± 0
	Normalized LWF average daily area burned per HTD with LWF (ha day^{-1})	2503 ± 1219	4593 ± 2325	6423± 3066	882 ± 295	1638 ± 715	3708 ± 1735
	Average LWF size (ha)	944 ± 244	1934 ± 530	2973 ± 901	536 ± 153	1358 ± 513	4612 ± 2159
	LWF area burned during HTD / LWF total area burned (%)	26.2	34.7	39.4	19.9	35.8	45.8
Non-HTD	Number of days classified as non-HTD		2283			2246	
	Non-HTD with LWF (%)	8.6	1.6	0.7	12	2.9	0.7
	Normalized LWF average number per non-HTD with LWF	1.4 ± 0.10	1.2 ± 0.09	1.1 ± 0.10	1.2 ± 0.05	0.9 ± 0.06	0.80 ± 0
	Normalized LWF average daily area burned per non-HTD with LWF (ha day^{-1})	541 ± 91	1972 ± 487	2815 ± 922	290 ± 23	711 ± 96	1097 ± 715
	Average LWF size (ha)	396 ± 50	1371 ± 268	2682 ± 696	243 ± 11	788 ± 63	1364 ±129
	LWF area burned during non-HTD / LWF total area burned (%)	73.8	65.3	60.6	80.1	64.2	54.2

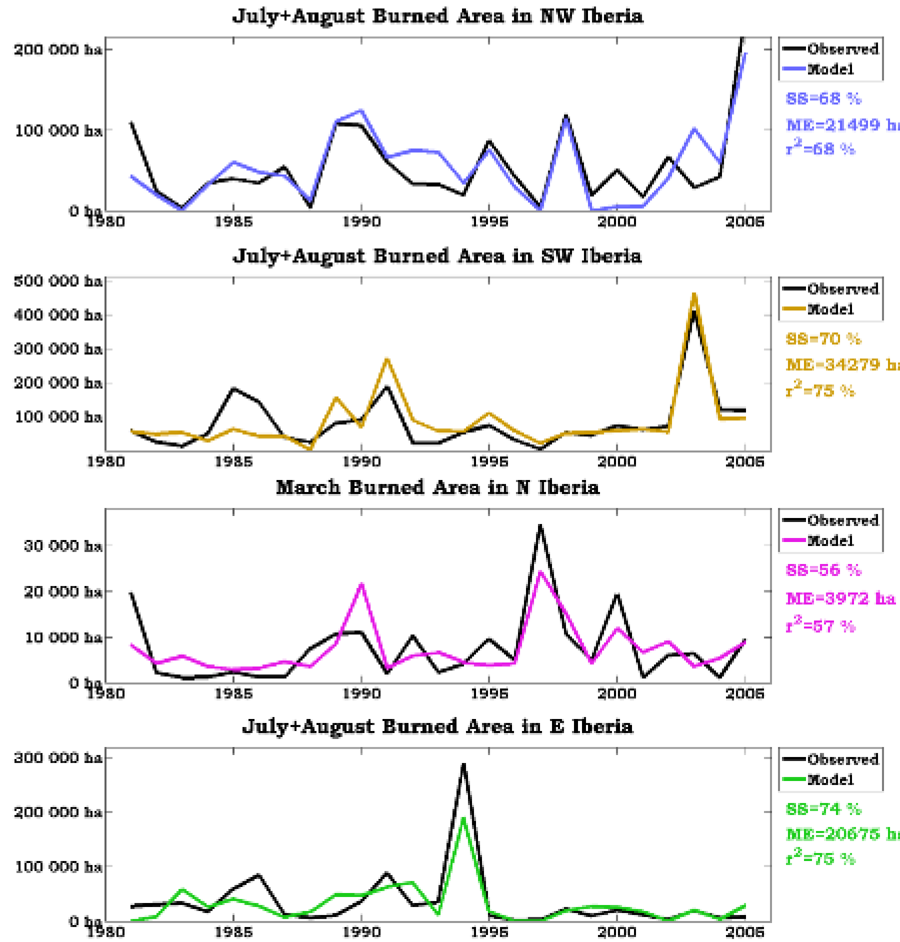
Cardil et al., 2013

Spatial and temporal variability of burnt area in the IP and on the construction of statistical models to reproduce the inter-annual variability

Cluster analysis to identify larger regions with similar fire regimes

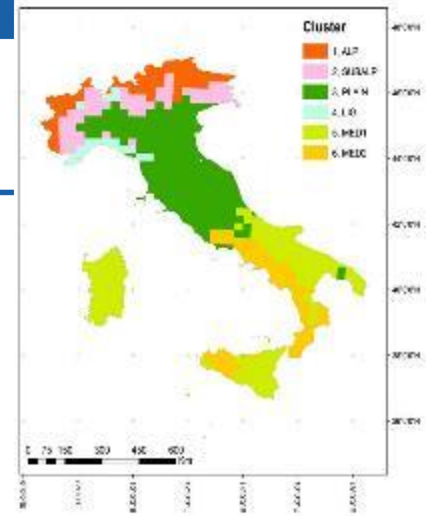


Spatial extension of the 4 clusters retained



Observed (black lines) and modeled (colored lines) series for Burnt Area in each of the considered clusters of the IP during 1981-2005

“Analysis of weather conditions influencing fire regime in Italy (1985-2008)”



Cluster	FIRE NUMBER r^2	FIRE NUMBER Significant variable	BURNED AREA r^2	BURNED AREA Significant variable
ALP	0.54	RH, Tn, Tx	0.54	RH, Tn, Tx
SUBALP	0.57	R, RH, Tn,Tx	0.54	R, Tn, Tx, RH
PLAIN	0.62	RH, R, Tx, Tn	0.53	RH, R, Tx, Tn
LIG	0.36	R, RH	0.37	RH, R, Tx, Tn
MED1	0.80	Tx, R, RH	0.76	Tx, R, RH
MED2	0.69	Tx, RH, R	0.67	Tx, R, RH
ITALY	0.62	RH, R, Tx, Tn	0.55	RH, R, Tx, Tn

Overall, the most important predictor of both FN and BA was RH, followed by R and Tx, accounting for the 62% and 55% explained variance, respectively

Northern clusters RH and R
Southern clusters Tx

Cluster	SEASON	FIRE NUMBER r^2	FIRE NUMBER Significant variable	BURNED AREA r^2	BURNED AREA Significant variable
ALP	MAM	0.72	Tn, RH, R	0.63	Tn, RH
SUBALP	MAM	0.70	Tn, RH	0.67	Tn, RH
PLAIN	JJA	0.62	Tx, Tn, R	0.58	Tx
LIG	MAM	0.71	Tn, RH, Tx	0.72	Tn, RH, Tx
MED1	JJA	0.66	Tx, R	0.71	Tx, R
MED2	JJA	0.87	Tx, RH	0.86	Tx, RH

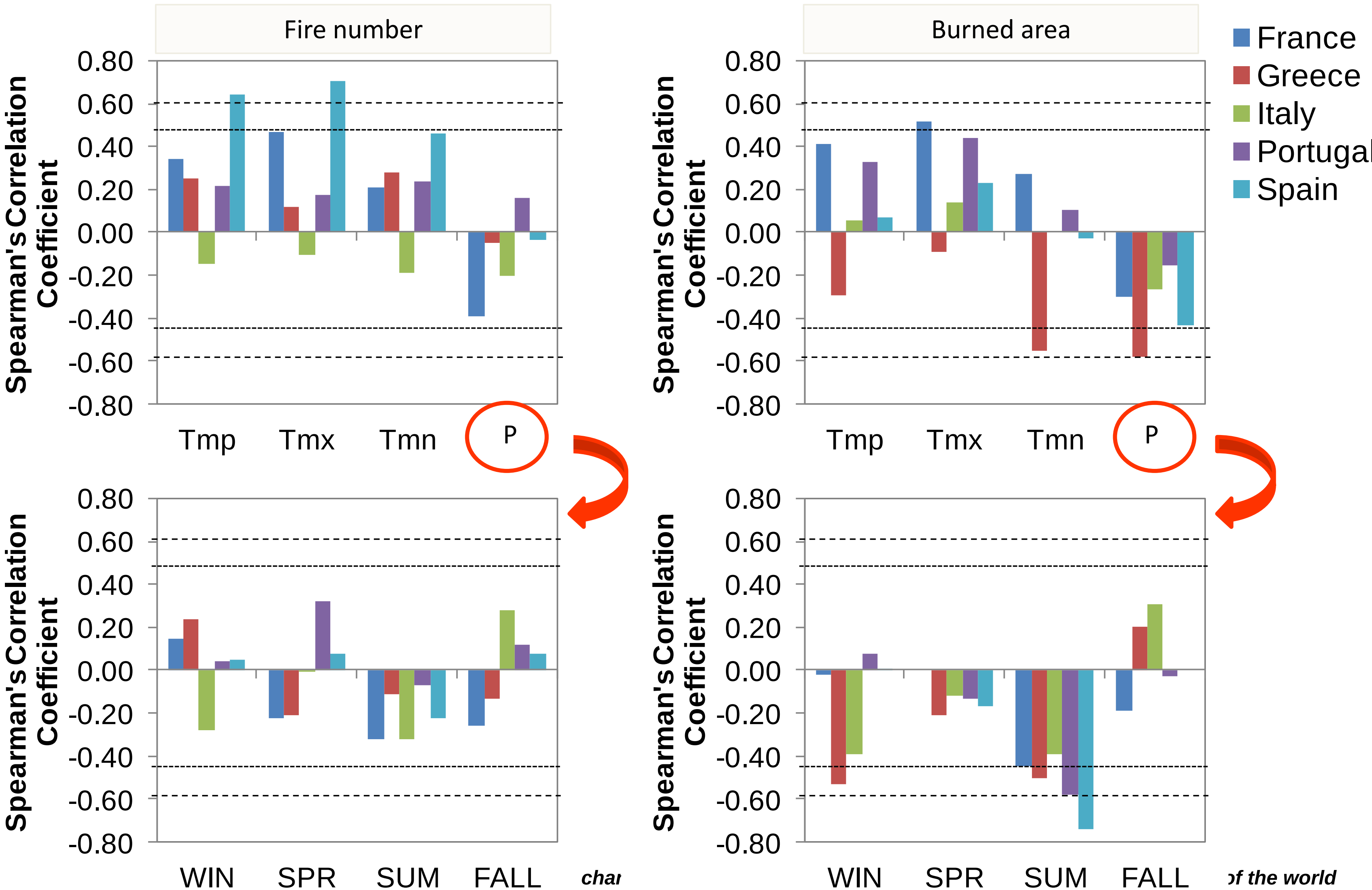
MED1 and MED2 highest correlation during JJA (above the 65%).

ALP, SUBALP and LIG during MMA (above 60%)

Bacciu et al., 2013

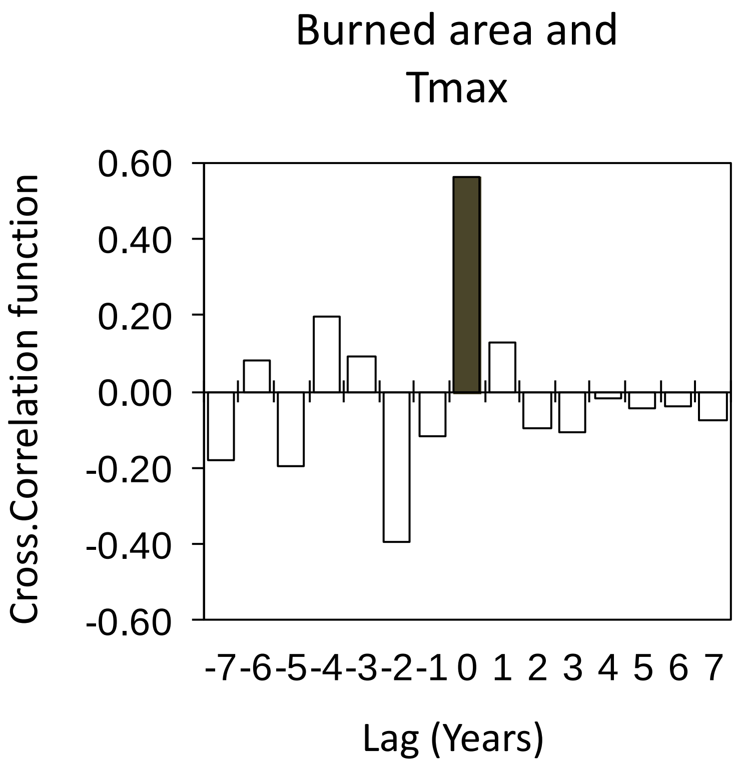
FIRE-WEATHER RELATIONSHIPS

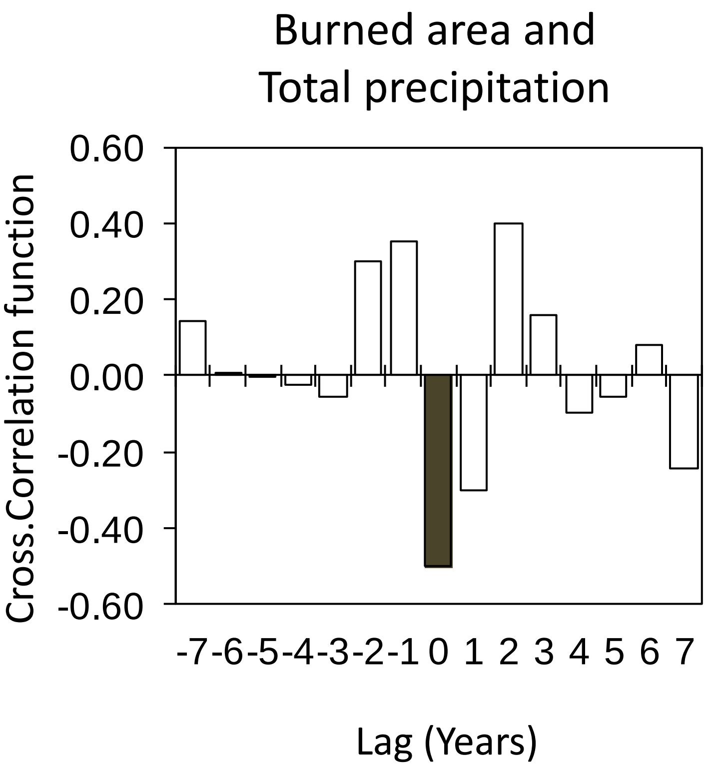
Correlation significance level ------ 99% --------- 95%

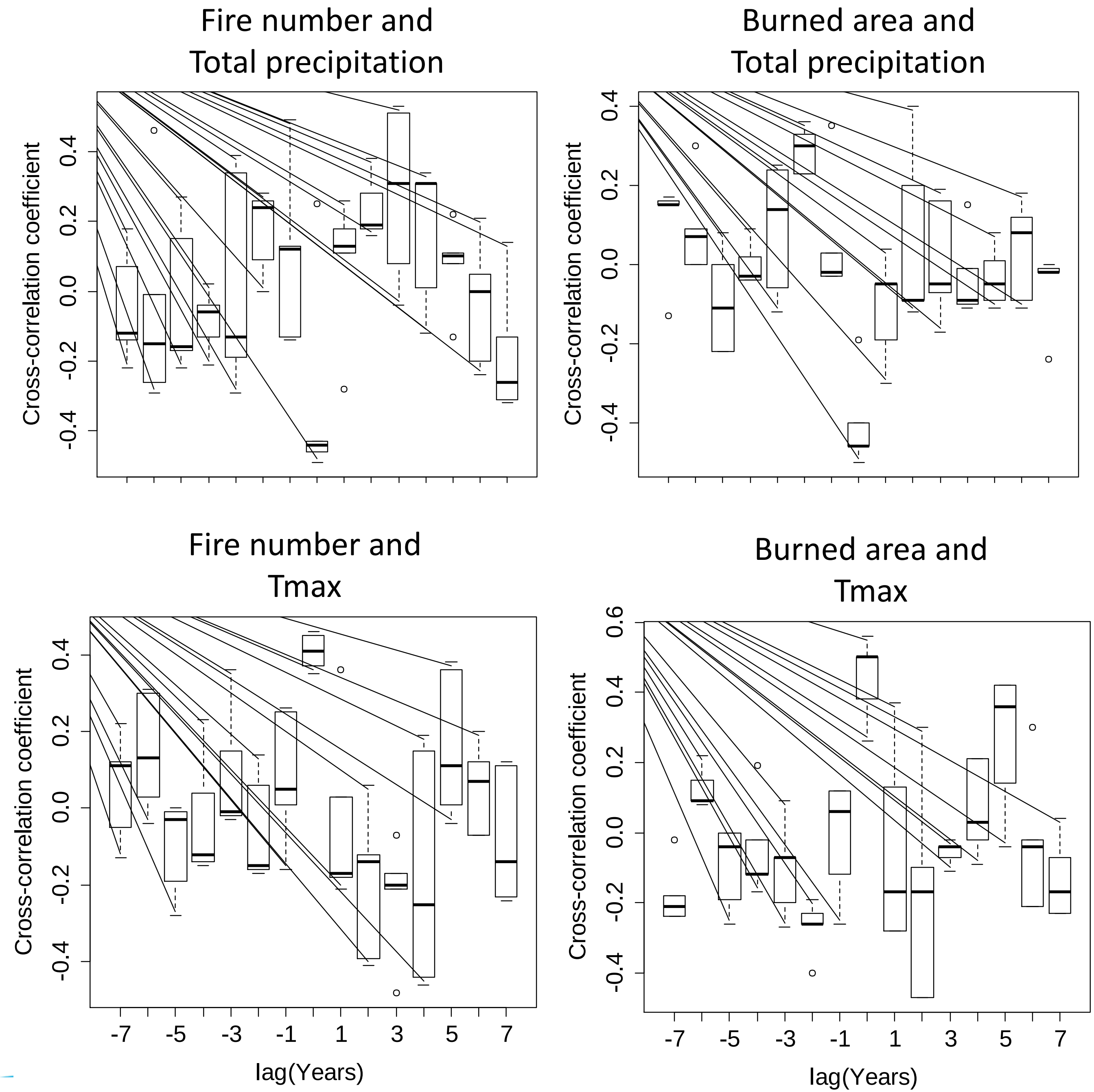


FIRE-WEATHER RELATIONSHIPS

Italy







FIRE-WEATHER RELATIONSHIPS

In 4 out to 5 countries FN & BA are significatively and negativey correlated with total annual precipitation at lag 0

2 out to 5 FN at lag3

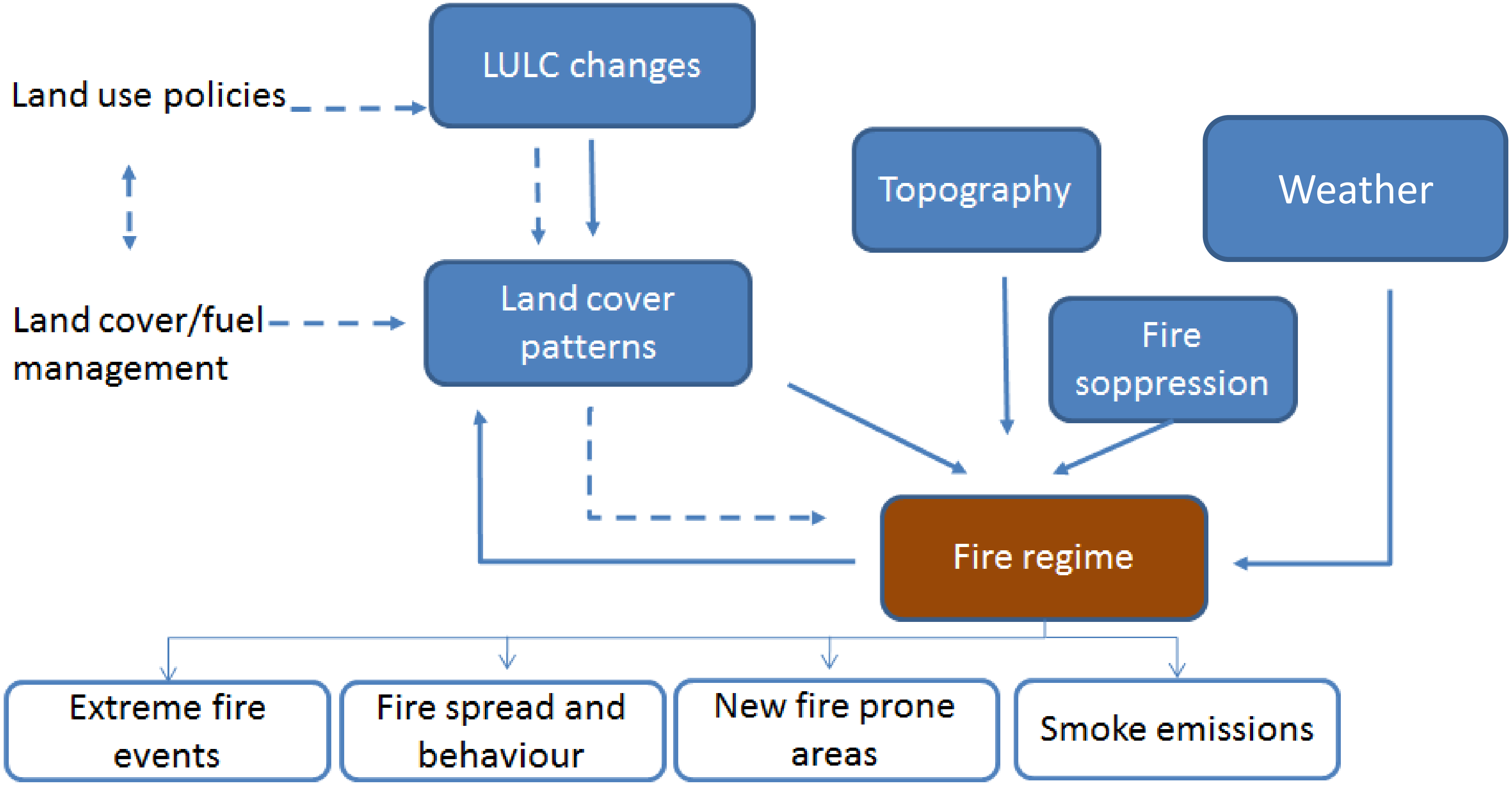
In 3 out to 5 countries FN & BA are significatively and positively correlated with Tmax at lag 0

ther fire-affected areas of the world

5. Changements récents

Recent changes in fire regime

In Southern Europe, fire frequency and wildfire extent **significantly increased after the 1970s** compared with previous decades



Recent changes in fire regime

Table 1 How humans influence fire regime parameters by modifying key variables that affect fire activity.

Fire variable	Natural influences	Human influences	Fire regime parameters
Wind speed	Season Weather Topography Land cover	Climate change Land cover change	Fire spread
Fuel continuity	Terrain type (slope, rockiness, aspect) Rivers and water bodies Season Vegetation (type, age, phenology)	Artificial barriers (roads, fuel breaks) Habitat fragmentation (fields) Exotic grasses Land management (patch burning, fuel treatments) Fire suppression	
Fuel loads	Tree, shrub and grass cover Natural disturbances (e.g. insect or frost damage, windthrow) Herbivory Soil fertility Season	Grazing Timber harvests Exotic species establishment Fire suppression Fuel treatments Land use and land cover (deforestation, agriculture, plantations)	Fire intensity and severity
Fuel moisture	Season Antecedent precipitation Relative humidity Air temperature Soil moisture	Climate change Land management (logging, grazing, patch burning) Vegetation type and structure (species composition, cover, stem density)	
Ignition	Lightning Volcanoes Season	Human population size Land management Road networks Arson Time of day Season Weather conditions	Number and spatial and temporal patterns of fires

Bowman et al., J Biogeogr. 2011

Recent changes in fire regime

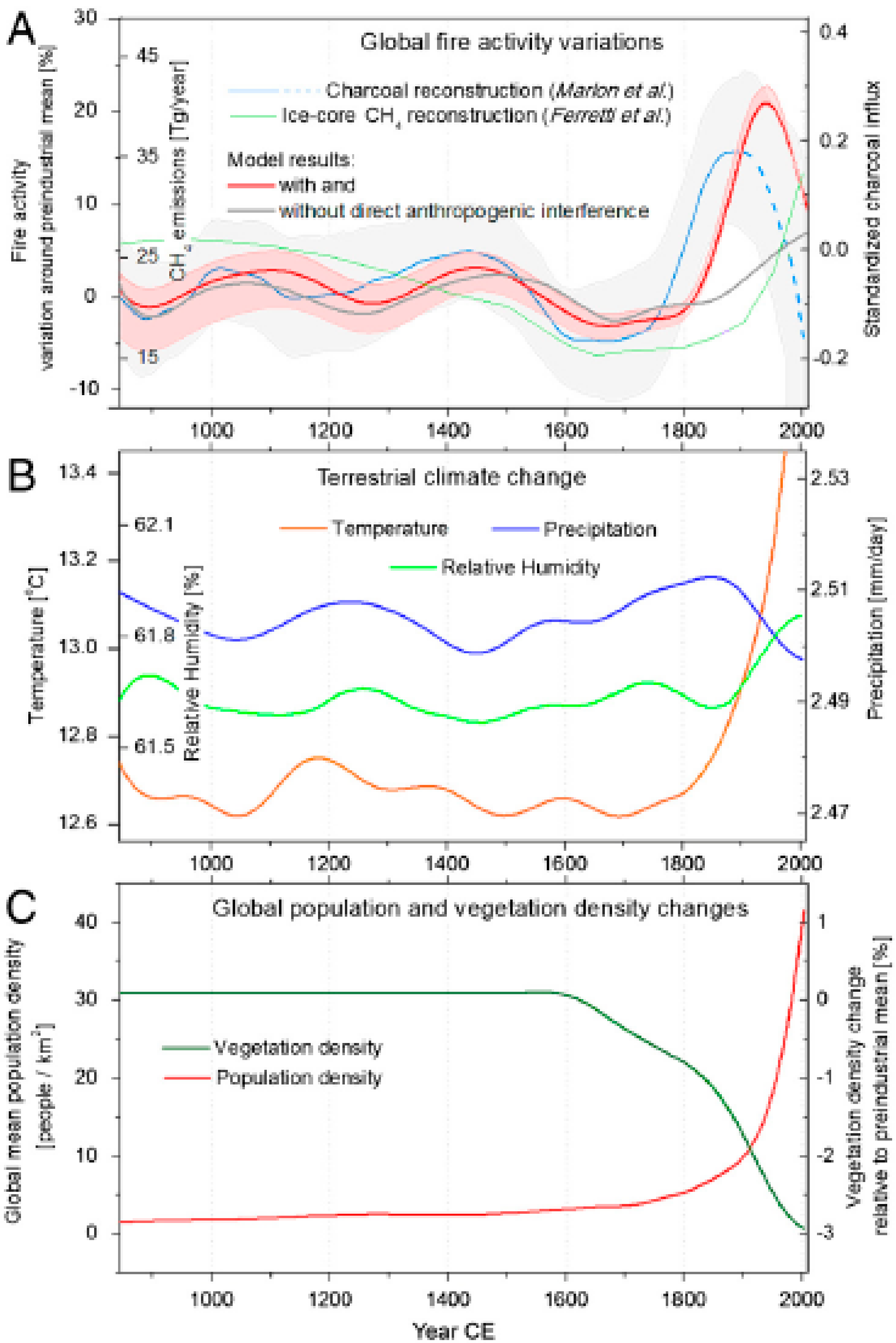
Table 2 Examples of how fire regimes have changed during the industrial era, from a representative cross-section of biomes from low to high latitudes. This ongoing transition is described in Fig. 3, in which pre-industrial fire regimes correspond to pyric phases C and D, and post-industrial fire regimes correspond to pyric phases E and F.

Biome	Pre-industrial fire regime	Post-industrial fire regime
Tropical rain forest	Very infrequent low-intensity surface fires with negligible long-term effects on biodiversity	Frequent surface fires associated with forest clearance causing a switch to flammable grassland or agricultural fields
Tropical savanna	Frequent fires in dry season causing spatial heterogeneity in tree density	Reduced fire due to heavy grazing causing increased woody species recruitment
Mid-latitude desert	Infrequent fires following wet periods that enable fuel build-up	Frequent fires due to the introduction of alien flammable grasses
Mid-latitude North American seasonally dry forests	Frequent low-intensity surface fires limiting recruitment of trees	Fire suppression causing high densities of juveniles and infrequent high-intensity crown fires
Boreal forest	Infrequent high-intensity crown fires causing replacement of entire forest stands	Increased high-intensity wildfires associated with global warming causing loss of soil carbon and switch to treeless vegetation

Bowman et al., J Biogeogr. 2011

Effect of Altered Fire regime on Ecosystems processes

The carbon cycle.	Extensive and very intense wildfires due to fuel accumulation will oxidize large quantities of carbon, and might diminish average carbon storage in the long term (van der Werf et al. 2004, Zimov et al. 1999).
Nutrient cycling.	accumulation of nutrients in fuels, with a larger proportion in relatively non-decomposable coarser materials (Boerner 1982, Christensen 1977, Mac-Kenzie et al. 2004).
Hydrologic flows and erosion	Increased runoff and associated erosion following fire are well documented in many ecosystems (Cannon 2001, Kirchner et al. 2001, Swanson 1981).
Community changes	lower diversity and loss of rarer elements. Increased woody litter can reduce postfire diversity patterns and, in some cases, create more uniform fuels and reduced postfire spatial variability (Rocca 2004).
Landscape changes	Landscape patch dynamics at large spatial scales can be disrupted by removal of fire (Baker 1994).

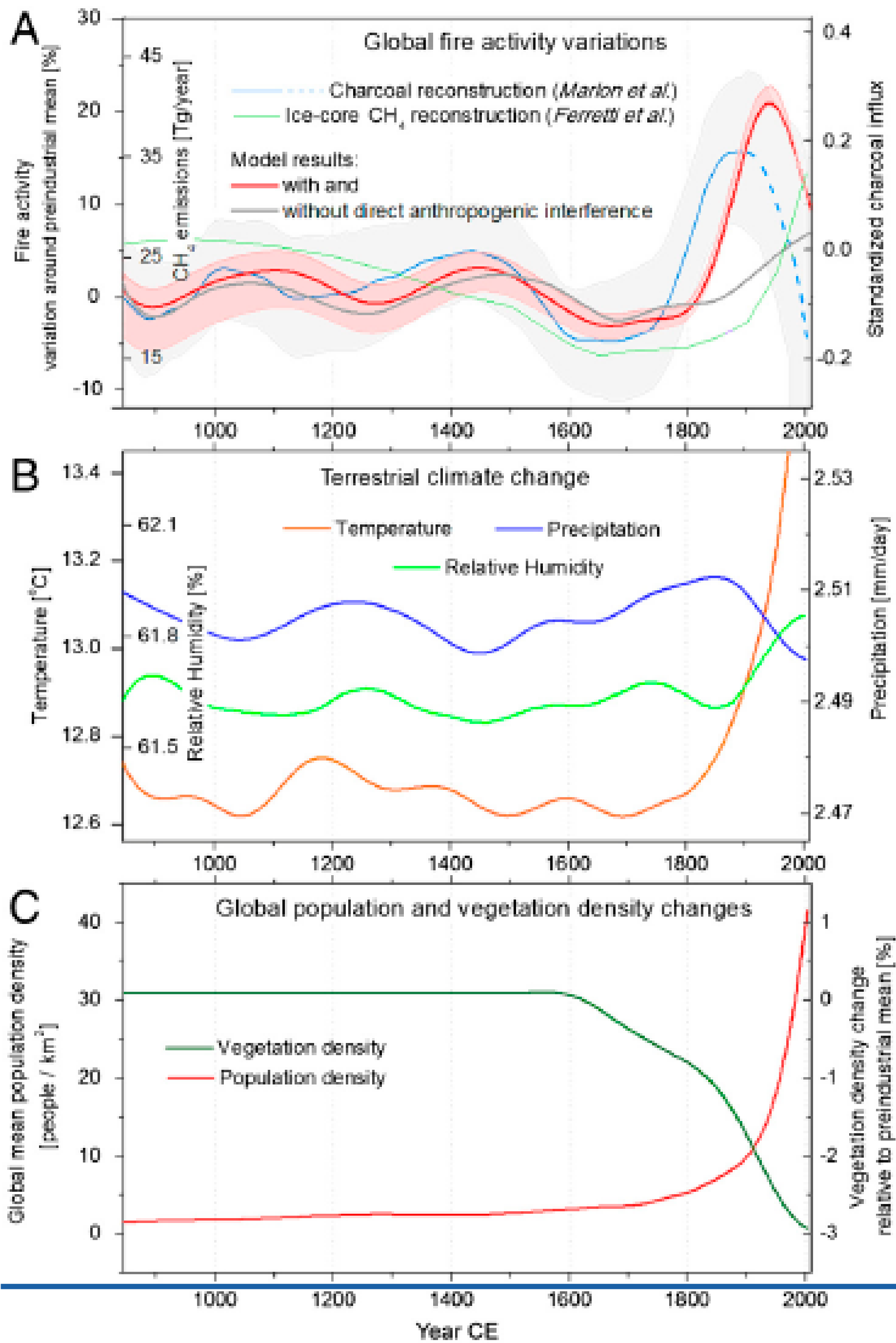


Recent changes in fire regime

Global wildfires

- Model results successfully recreate global fire activity variations reconstructed from sedimentary charcoal records
- Simulations either with or without direct anthropogenic influence agree well with reconstructed data, suggesting that during this period global fire activity was primarily climate-driven, whereas human influence remained relatively small.
- Changes in global precipitation, rather than temperature, played a major role in determining global fire activity variations in the preindustrial period

Source: Pechony and Shindell, 2010



Recent changes in fire regime

Global wildfires

➢After Industrial Revolution human population expanded rapidly (Fig. 1C).

➢Unprecedented rates of fossil fuel burning led to the onset of global warming (Fig. 1B).

➢Over the 19th century both the model- and the charcoal-based records show sharp increases in biomass burning (Fig. 1A).

Model results suggest a stronger influence from direct anthropogenic activities

Source: Pechony and Shindell, 2010

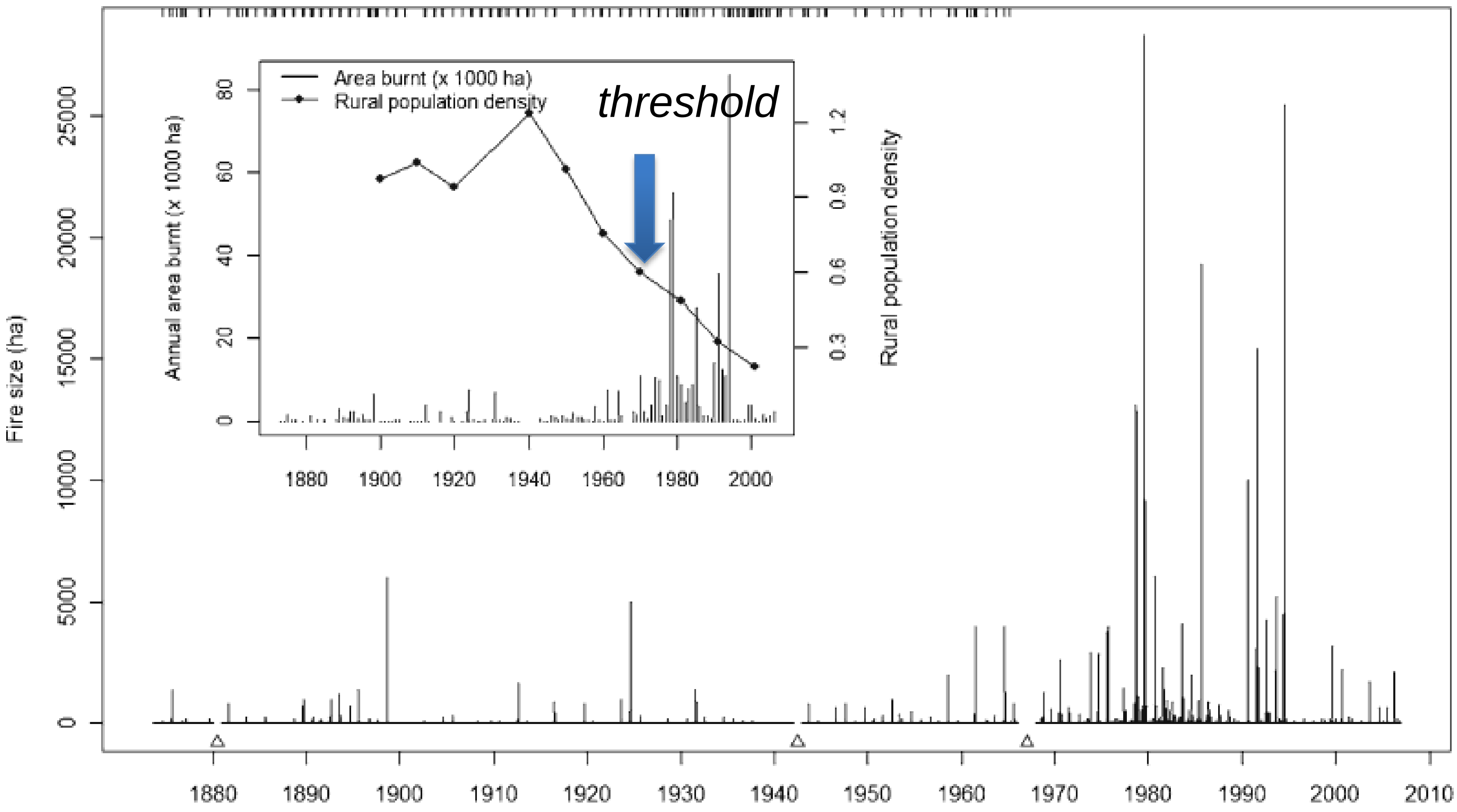
Recent changes in fire regime

MEDITERRANEAN BASIN

Pausas & Fernández-Muñoz (2011) Hypotesis

- Fire activity was lower during the pre fire statistics period (<60s) because of the lower fuel
- The depopulation of rural areas changed landscape (fuel) structure and thus it should increased fire activity
- Recent variability in area burnt is climatically driven
- Consequently, the relative role of human and climate shifted during the recent history

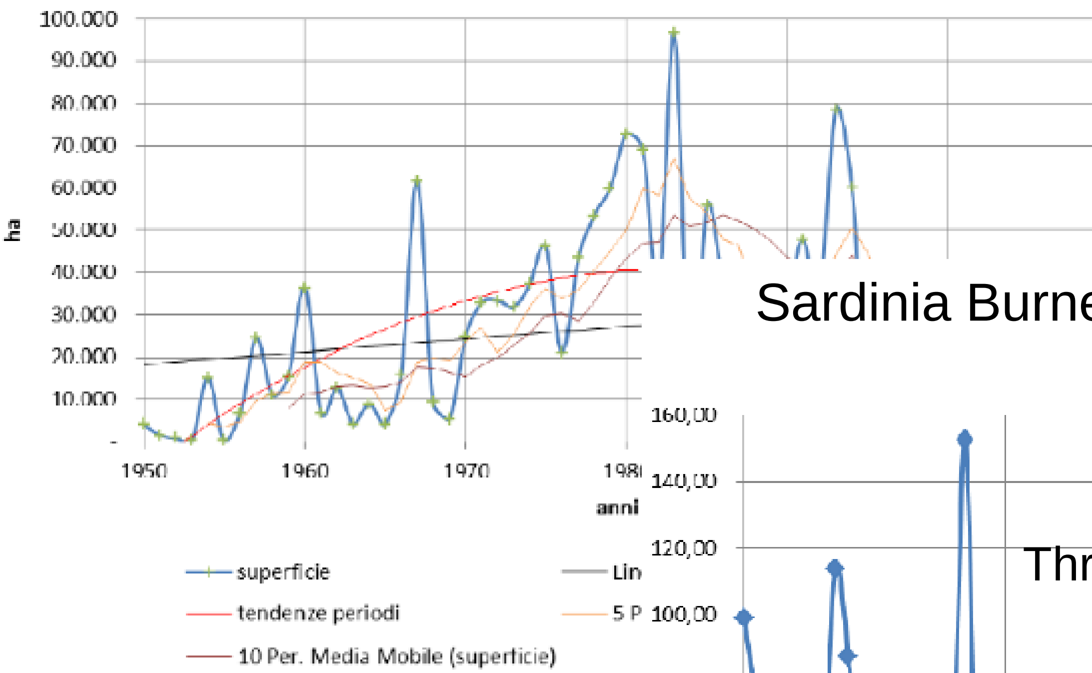
Recent changes in fire regime



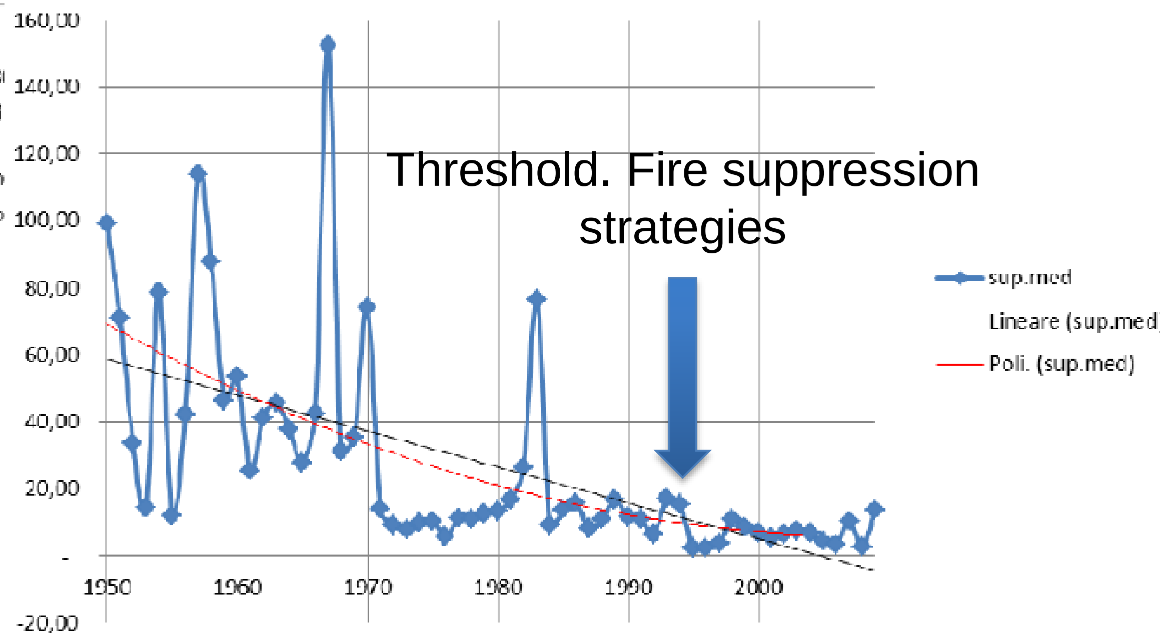
Source: Pausas & Fernández-Muñoz, 2011

Recent changes in fire regime

Sardinia Burned Area – 1950-2009



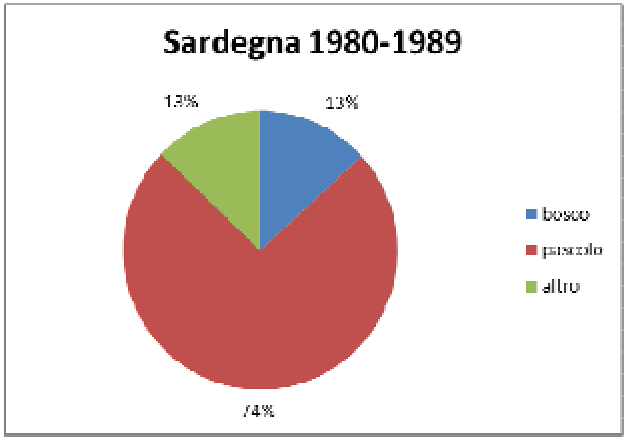
Sardinia Burned Area/Fire – 1950-2009

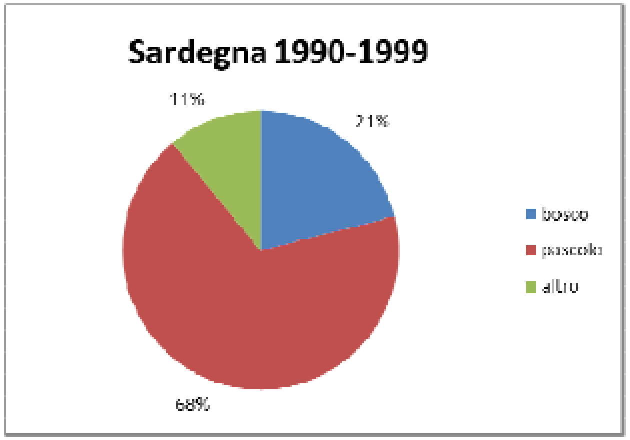


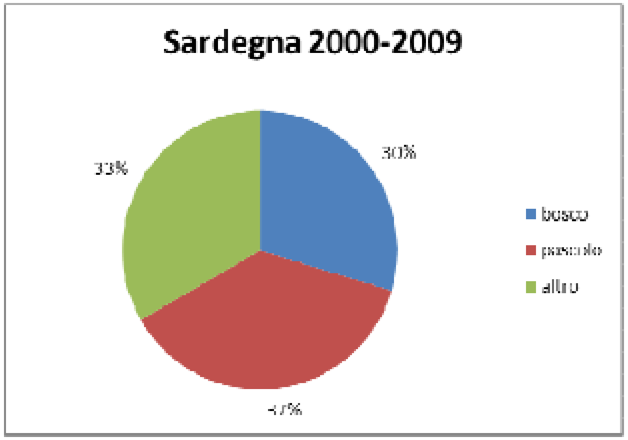
Source: Proterina C project 2011

Recent changes in fire regime

Sardinia Burned Area







Grassland and pasture burned areas decreased significantly from 70s to 2000:

70s = 80-90%

80s = 74%

90s = 68%

2000 = 37%

Source: Proterina C project 2011

Recent changes in fire regime

- Grassland and pasture burned area contraction due to changes on pastoralism dynamics and to more environmental protection policies

- Shift toward coastal areas, due to the turism development and actions linked to the costal area depreciation

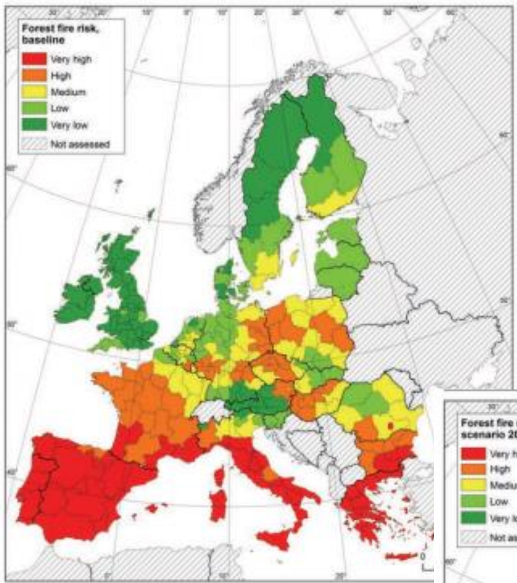
- Contraction of burned area, due to an high improvement of fire fighting, suppression technologies, and more organization (Boni, 2004)

6. Projections futures

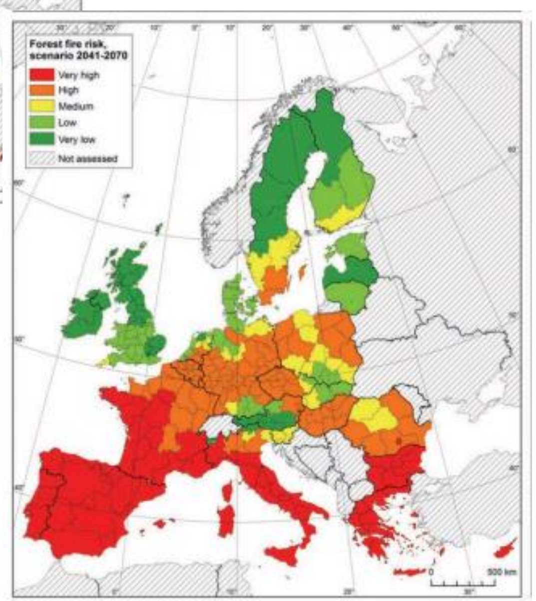
“Wildfire risk in Southern Europe [***high confidence***] may also increase due to climate change”

IPCC, 2014

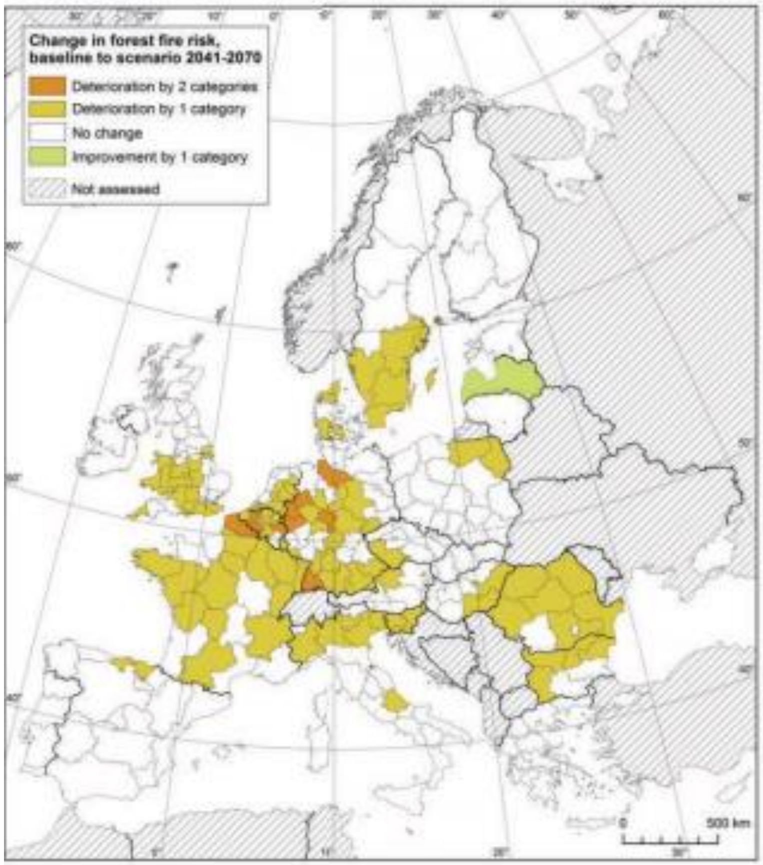
baseline



2041-2070



Changes of categories from baseline to 2041–2070.

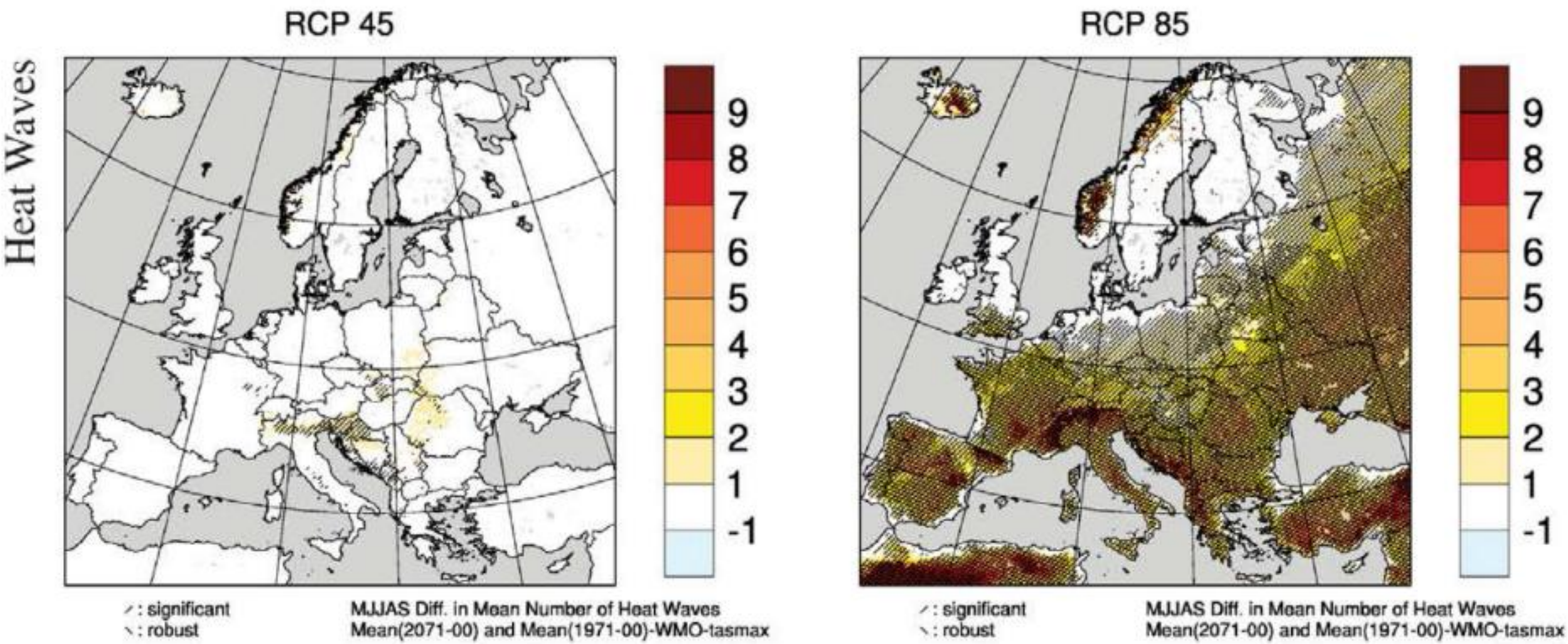


Northwards expansion of very high and high fire risk

Source: Lung et al., 2013

Climate change impacts on fire

Projected changes in the mean number of heat waves occurring in the months May to September for the period 2071-2100 compared to 1971-2000 (number per 30 years).



Heat wave = more than 5 consecutive days with daily Tmax > mean Tmax of the May-Sept season (1971-2000) by at least 5° C.

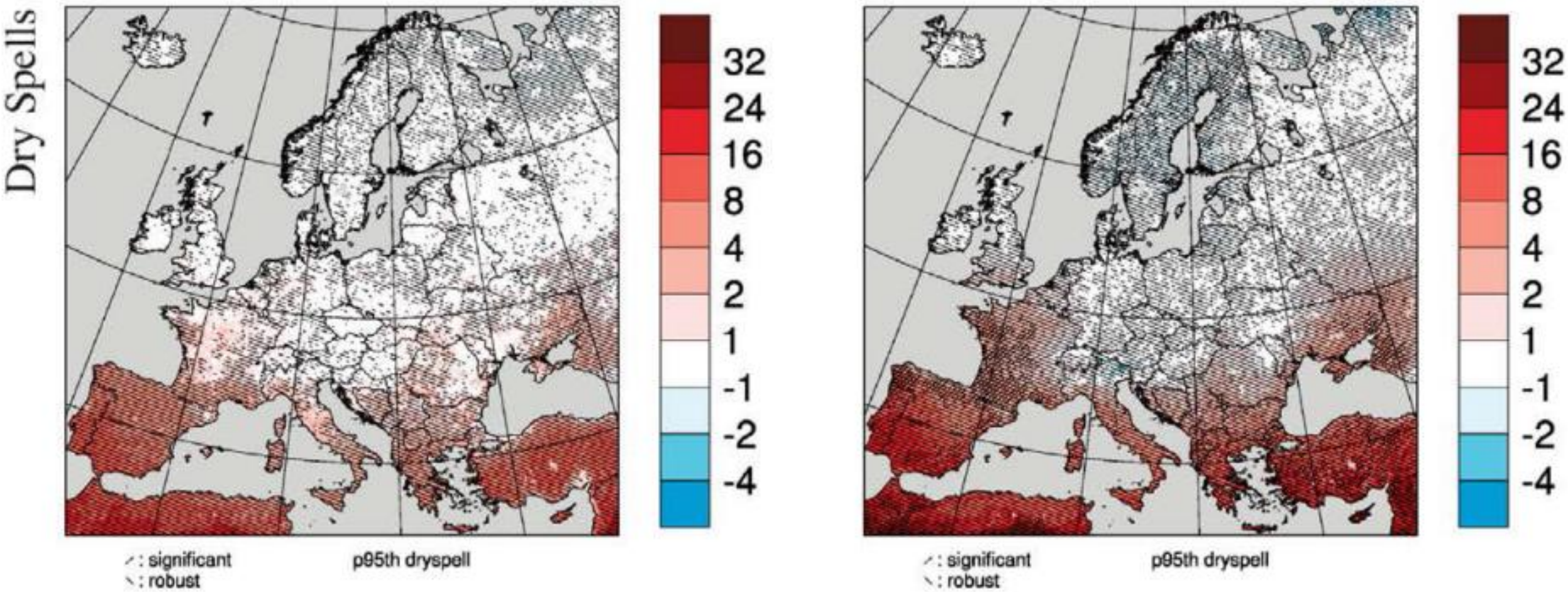
Adapted from Jacob et al. (2013)

Climate change impacts on fire

Projected changes in the 95th percentile of the length of dry spells for the period 2071-2100 compared to 1971-2000 (in days).

RCP 45

RCP 85



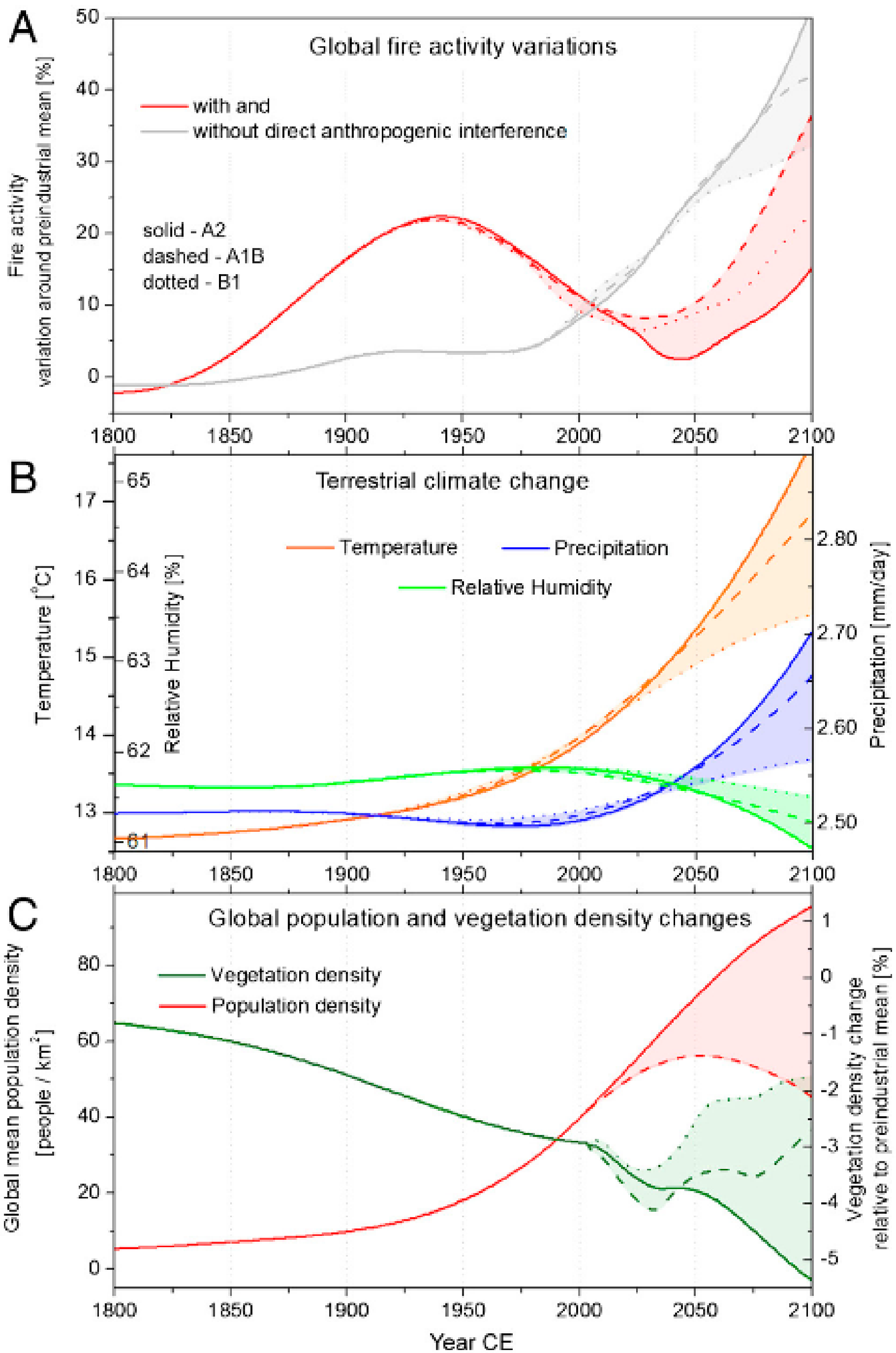
Dry spells are defined as periods of at least 5 consecutive days with daily precipitation below 1mm

Adapted from Jacob et al. (2013)

Climate change impacts on fire

Future **wildfire risk** is projected to increase in Southern Europe (Carvalho *et al.*, 2011; Dury *et al.*, 2011; Lindner *et al.*, 2010; Vilén and Fernandes, 2011), with an **increase in the occurrence of high fire danger days** (Arca *et al.*, 2012; Lung *et al.*, 2012) and in **fire season length** (Pellizzaro *et al.*, 2010). The annual **burned area** is projected to increase by a factor of 3 to 5 in Southern Europe compared to the present under the A2 scenario by 2100 (Dury *et al.*, 2011).

IPCC, 2014



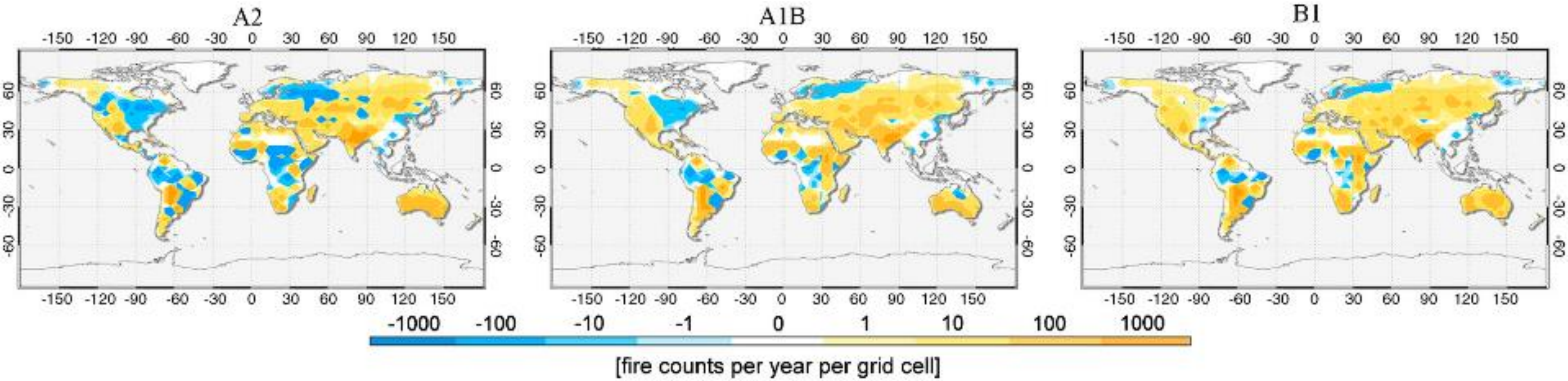
Future trends in Fire Regimes

- GISS GCM climate simulations predict a significant warming over the forthcoming century (Fig. 2B).
- Rapidly rising temperatures and regional drying reverse the recent fire activity decline, driving a rapid increase after ~2050 in all three scenarios examined here
- Population growth, and to a lesser extent, land-cover change (Fig. 2C), reduces the increase in fire activity

Source: Pechony and Shindell, 2010

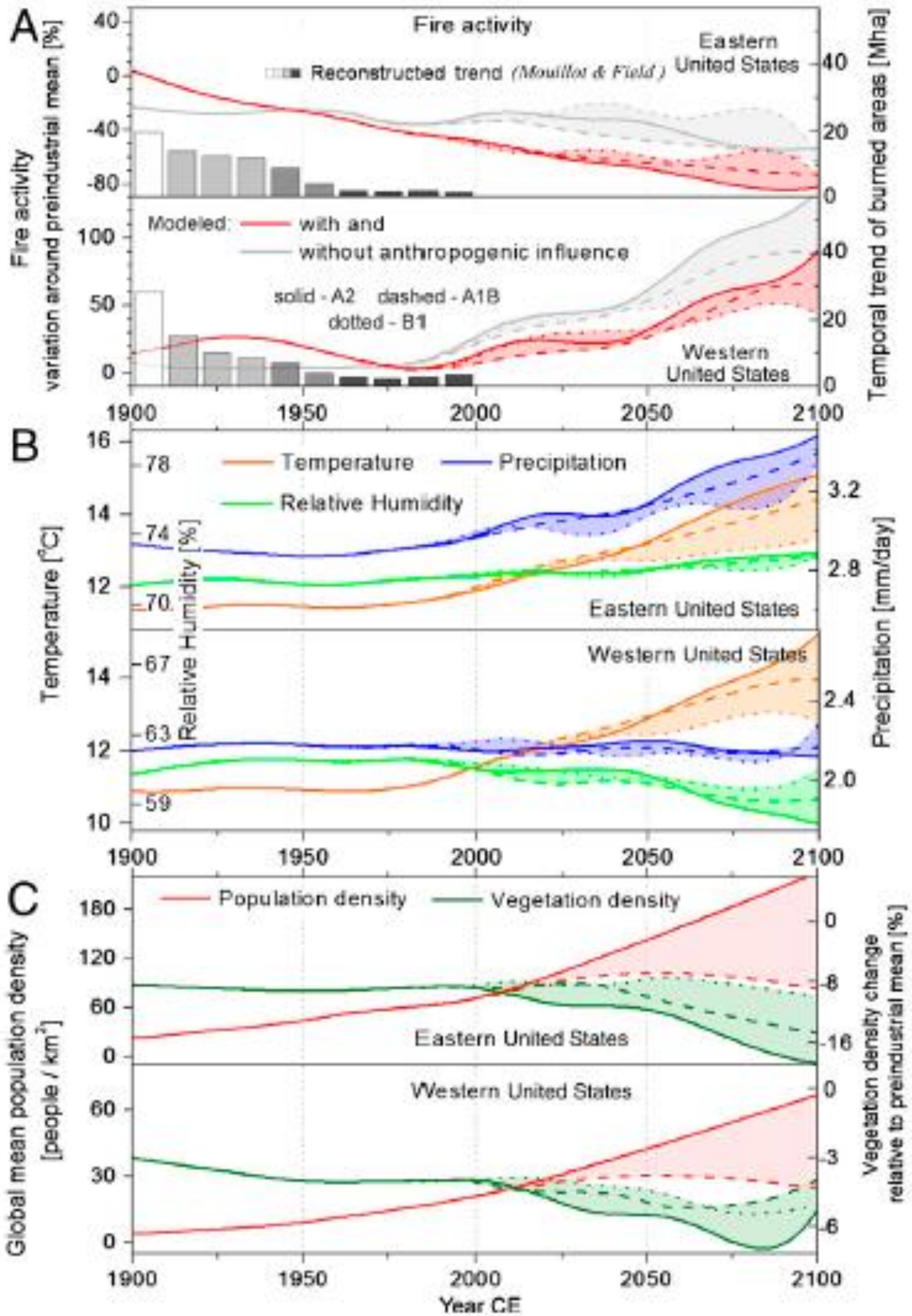
Future trends in Fire Regimes

This trend is not uniform worldwide



Regional patterns of projected fire activity changes. Yellow shades indicate increases, and blue shades indicate decreases in linearized regional fire activity trends over the 21st century (years 2004–2100) in A2, A1B, and B1 scenarios

Source: Pechony and Shindell, 2010



Future trends in Fire Regimes

- Although temperatures rise throughout the country, it becomes more humid and rainy in the East and drier in theWest (Fig. 4B).
- Consequently, in the eastern United States fire activity declines, while rising considerably in the western United States (Fig. 4A).
- In both cases increasing population densities and land-cover changes (Fig. 4C) generally reduce fire activity.

Source: Pechony and Shindell, 2010

Future trends in Fire Regimes

Portugal. Assessing the fire weather and subsequent fire activity under a $2xCO_2$ scenario using historical relationships and the HIRHAM (High Resolution Hamburg Model) 12 and 25 km climate simulations.
(Source: Carvalho et al., 2010)

Table 4 Annual area burned (ha) by district, observed in 1980–1990 period and predicted for the $2 \times CO_2$ climate, considering the average $2 \times CO_2/1 \times CO_2$ ratio between HIRHAM 12 km and HIRHAM 25 km simulations

District	Observed annual area burned (1980–1990)		$2 \times CO_2$ area burned		$(2 \times CO_2 - obs)/obs(\%)$
	(ha)	(%)	(ha)	(%)	
Bragança	2,804.5	5.3	20,837.4	6.8	643
Vila Real	5,717.1	10.8	29,185.8	9.5	411
Porto	2,970.5	5.6	20,956.9	6.8	606
Viseu	9,064.7	17.1	55,022.7	18.0	507
Coimbra	11,089.4	20.9	70861.3	23.2	539
Castelo Branco	6,897.5	13.0	47,523.8	15.5	589
Santarém	4,160.6	7.9	22,716.9	7.4	446
Lisboa	5,717.1	10.8	19,295.2	6.3	238
Portalegre, Évora and Beja	2,017.6	3.8	8,141.0	2.7	304
Faro	2,500.9	4.7	11479.2	3.8	359
All districts	52,939.9	100.0	306,020.1	100.0	478

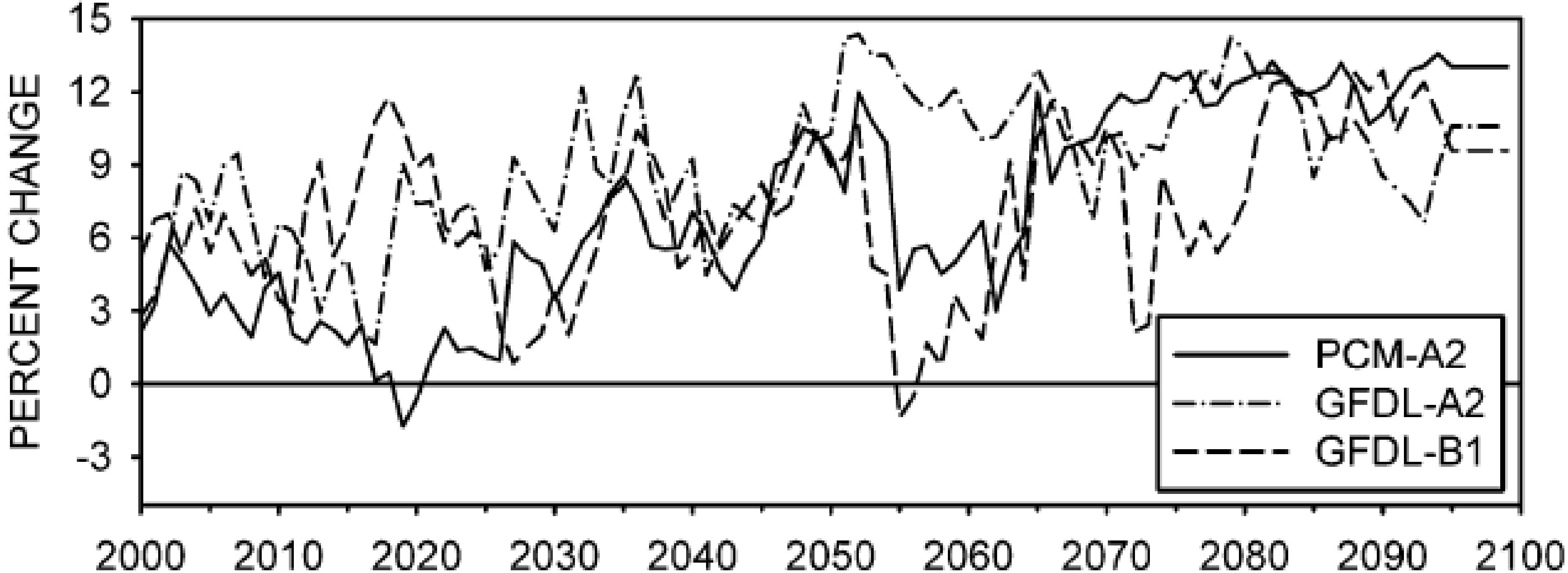
Percent of total annual area burned by district for observed and $2 \times CO_2$ scenario and percent of increase in area burned in future scenario

The projections for $2 \times CO_2$ scenario showed a substantial increase in area burned in all of the analyzed districts.

The country as a whole shows a **478%** increase in area burned. This future area burned equates to approximately **7.8%** of the burnable area

Future trends in Fire Regimes

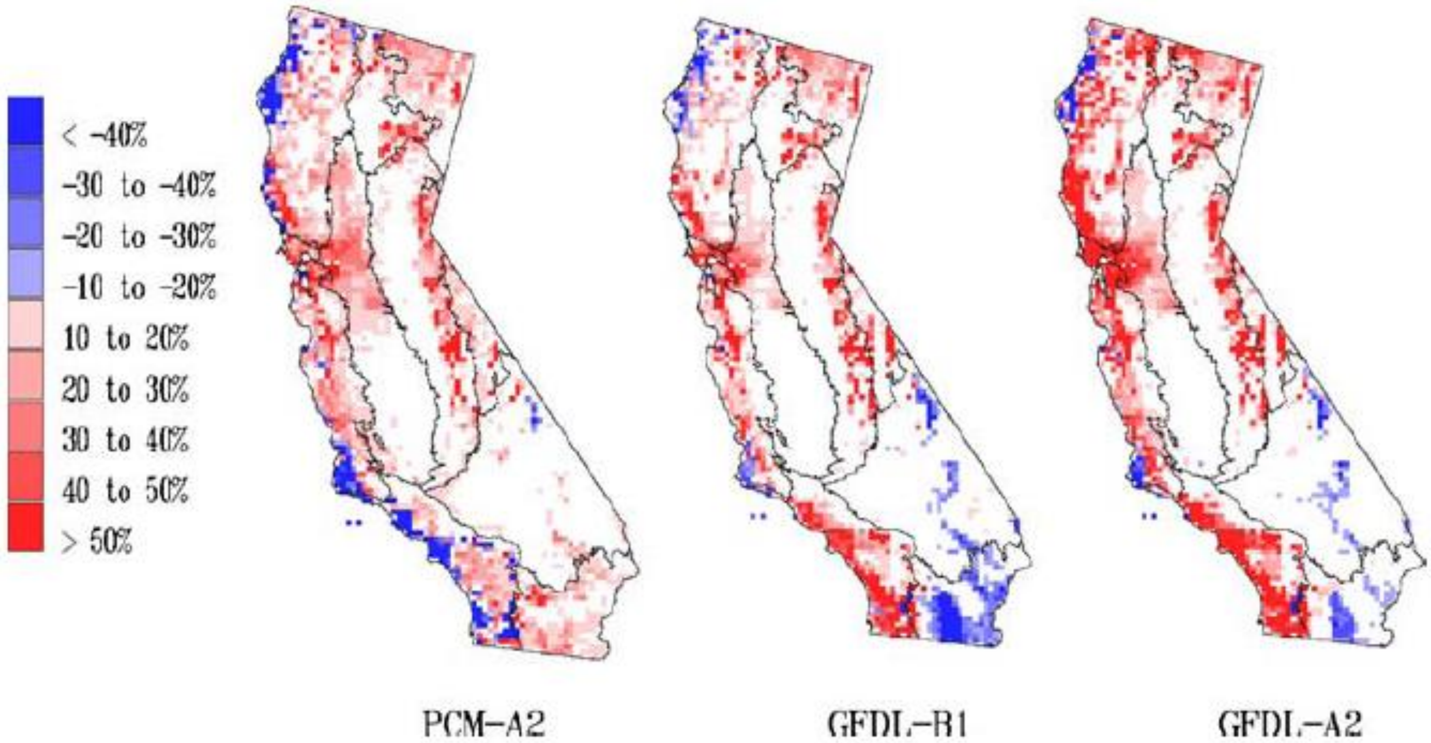
California. Percent change in annual total area burned with respect to the 1895–2003 historical period (source: Lenihan et al., 2008)



PCM-A2: no change in ppt., +2.5 to 3° C; GFDL-B1 scenario: slightly drier, +2.5 to 3° C; GFDL-A2: much drier, +4 to 5° C

Future trends in Fire Regimes

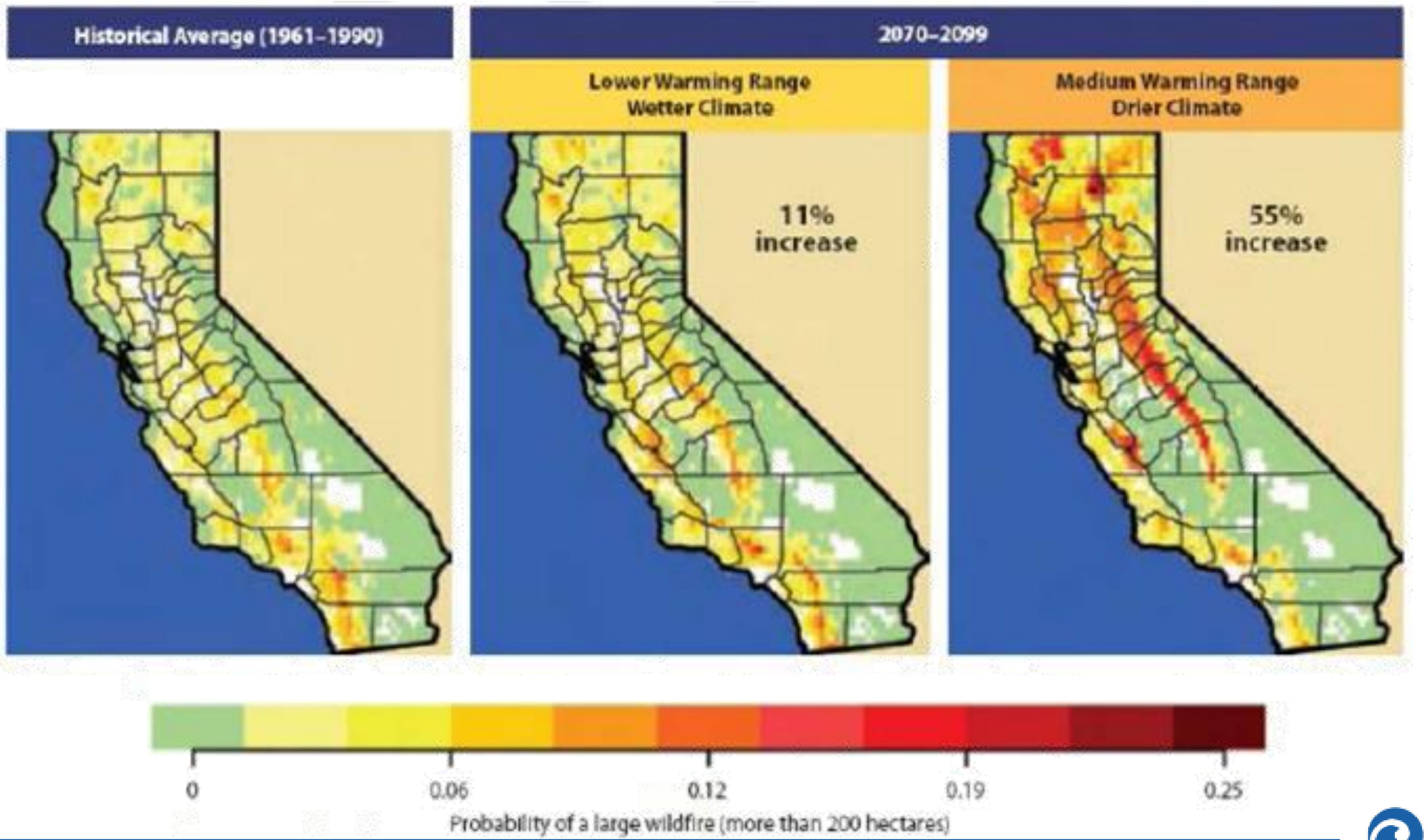
California. Models project increases in fire activity (source: Lenihan et al., 2008)



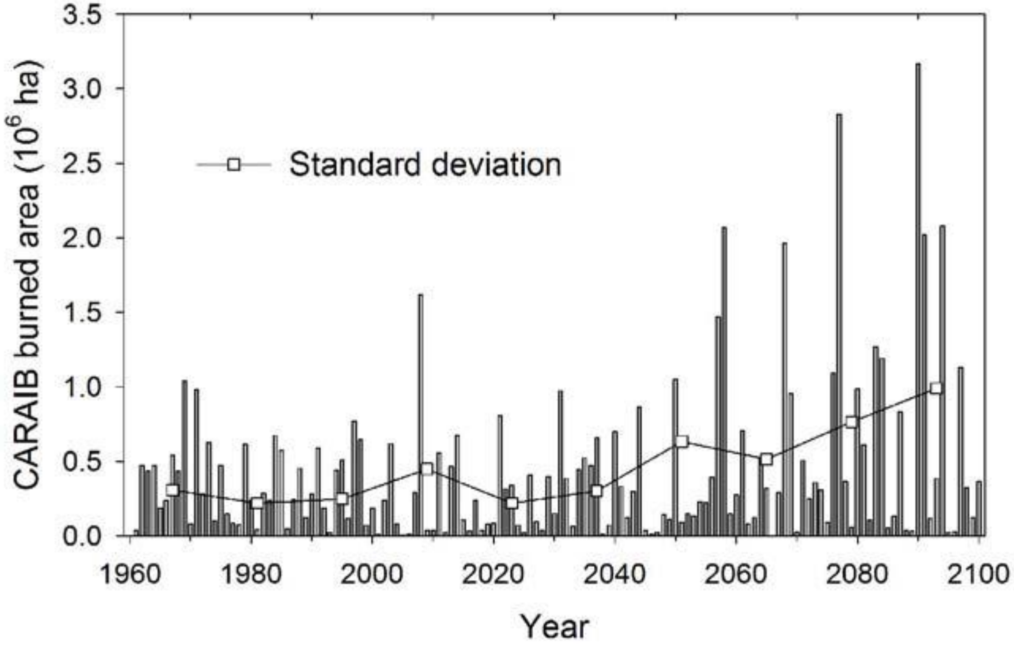
PCM-A2: no change in ppt., +2.5 to 3° C; GFDL-B1 scenario: slightly drier, +2.5 to 3° C; GFDL-A2: much drier, +4 to 5° C

Future trends in Fire Regimes

California. Increasing probability of large Wildfires (source: State of California, 2009)



Increase of burned area



Area burned (10^6 ha) in the Mediterranean Region over the 1961-2100 period

Increased frequency of larger area burned fires

Source: Dury et al., 2011

Source: Carvalho et al., 2010

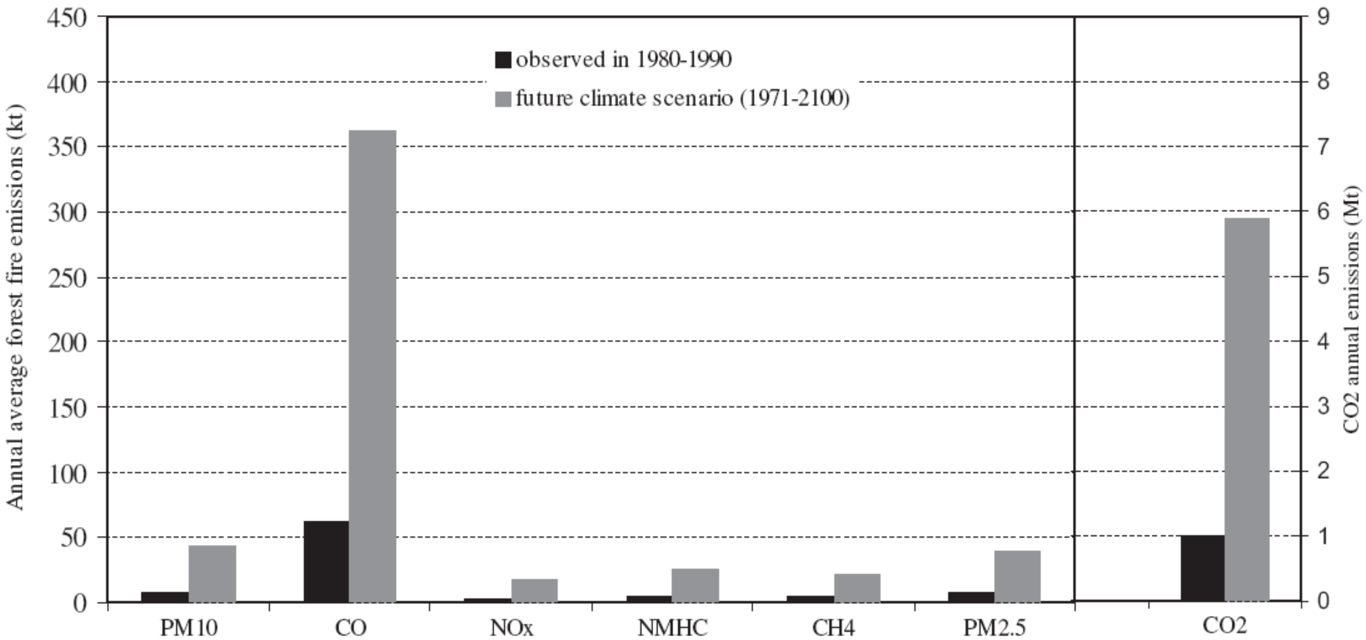
Annual area burned (ha) in Portugal, observed in 1980–1990 period and predicted for the 2 × CO_2 climate

District	Observed annual area burned (1980–1990)		2 × CO_2 area burned		(2 × CO_2 – obs)/obs(%)
	(ha)	(%)	(ha)	(%)	
All districts	52,939.9	100.0	306,020.1	100.0	478

Percent of total annual area burned by district for observed and 2 × CO_2 scenario and percent of increase in area burned in future scenario

Increase of GHG emissions due to biomass burning

Annual average forest fire emissions in Portugal for the reference period (1980-1990) and for the future climate (2071-2100) under the IPCC SRES A2 scenario



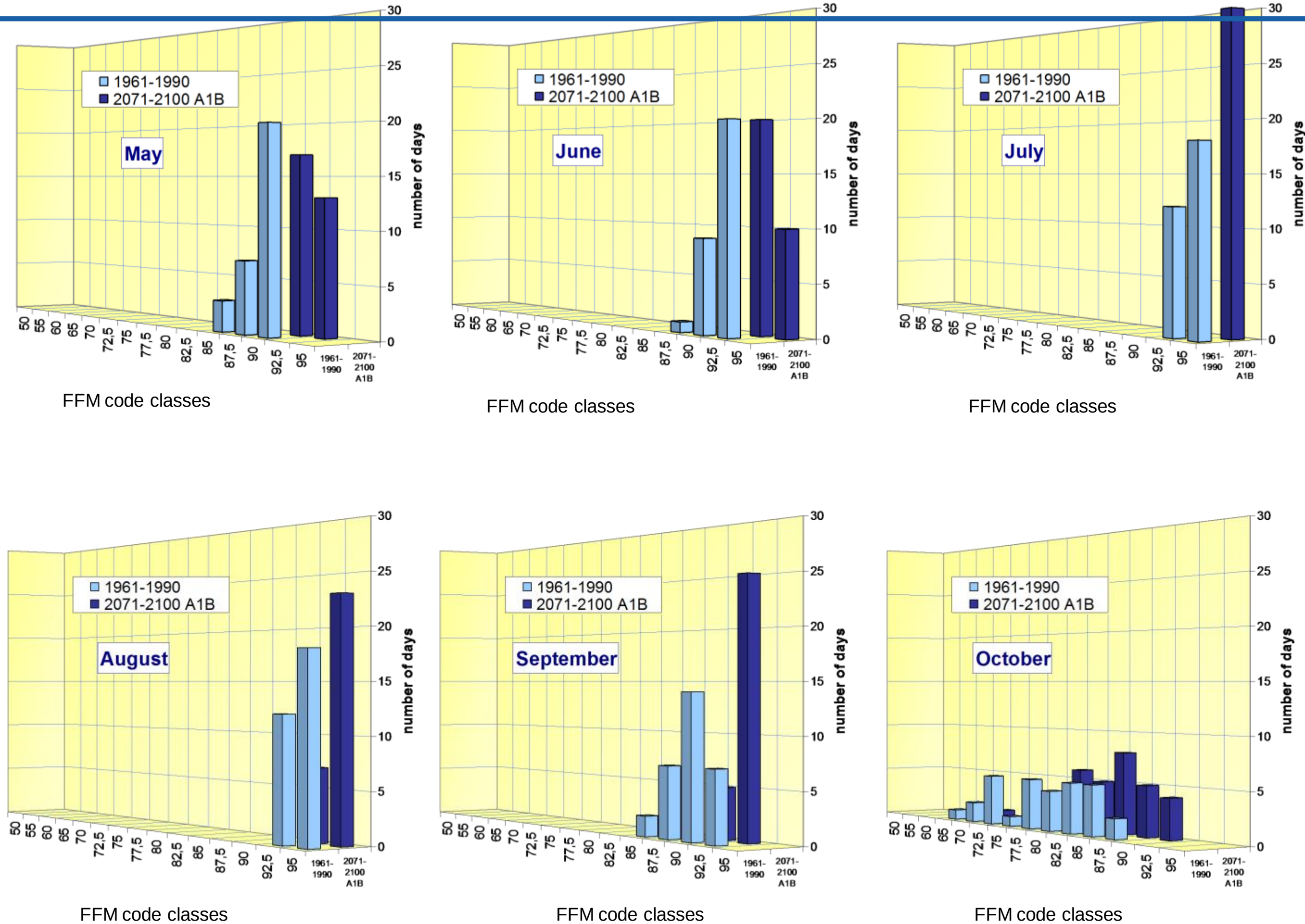
1980-1990 Annual CO_2 equivalent emissions = 1.27 Mt

2071-2100 Annual CO_2 equivalent emissions = 7.44 Mt

This represents an overall increase of approximately **500%**

Source: Carvalho et al., 2011

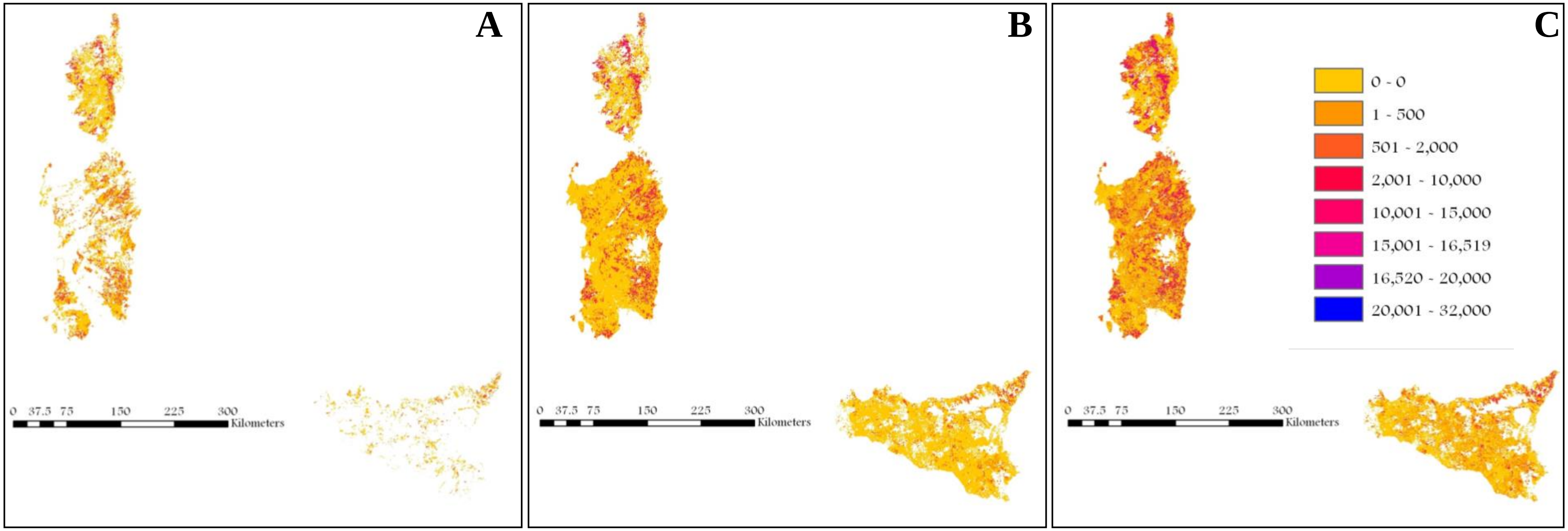
Future trends/Seasonality



Number of days for each FFM code class calculated using data from the Regional Climate Model (1961 - 1990: baseline; 2071 – 2100 A1B scenario) and relative to May-October months

Pellizzaro et al., 2010

Future trends/Fire Intensity



Mappe di **intensità del fronte di fiamma** (kW m^{-1}), considerando diversi percentili delle condizioni meteorologiche storiche: (A) 50° percentile, (B) 75° percentile, (C) 90° percentile.

Modificato da Salis et al. (2010)

شكرا Merçi **Thanks**

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Alan Ager, Mark Finney, Monia Santini, Bachisio Arca

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