



Climatica



ISSN: 2989-5391 (Online)

Publisher: Tomorrow's Research Publications (TRP)

An International Peer-Reviewed Open Access Journal

Journal homepage: <https://trpubonline.org/index.php/Climatica>

RESEARCH ARTICLE

Wildfire Risk Modeling Under Future Climate Projections in Mediterranean Ecosystems

Henrik Toth^{1*}, **Miguel Fernandez²** and **Laura Hansen³**¹Department of Renewable Energy and Climate Policy, Loire University Center for Climate Data Analysis, France²Department of Climate Science, Vistula Institute of Atmospheric Science, Poland³Institute for Climate Modeling and Data Analysis, Danube University Center for Climate Policy, Slovakia*Corresponding author: Henrik Toth, Department of Renewable Energy and Climate Policy, Loire University Center for Climate Data Analysis, France; Email: h.toth@lucda.fr

ABSTRACT

Fire weather in the Mediterranean Basin is projected to intensify as regional warming and summer drying outpace the global average, but the magnitude of that intensification, and its translation into burned area, remains poorly quantified at the sub-regional scale relevant to fire management planning. We computed the Canadian Forest Fire Weather Index (FWI) System daily across five Mediterranean sub-regions (Iberia, southern France, peninsular Italy, the Balkan Peninsula, and Greece and the Aegean) using a nine-member, bias-corrected EURO-CORDEX regional climate model ensemble at 0.11 degree resolution, driven under SSP2-4.5 and SSP5-8.5, and benchmarked the ensemble's historical (1991-2020) FWI distribution against ERA5-Land reanalysis and the Global Fire Weather Database before projecting fire danger to two future periods, 2041-2070 and 2071-2100. A regional empirical burned-area model, calibrated against 2001-2020 European Forest Fire Information System records using summer FWI percentiles, antecedent drought code, and land-cover fuel class as predictors, was then applied to the same ensemble to translate fire weather change into burned-area change. Averaged across the five sub-regions, the number of very-high-to-extreme fire danger days per year is projected to increase from a historical baseline of 21 days to 34 days (62% increase) under SSP2-4.5 and to 49 days (133% increase) under SSP5-8.5 by 2071-2100, with the largest absolute increases in Iberia and the Balkans and the largest proportional increases in currently cooler, wetter sub-regions such as the northern Balkans, where fire danger is projected to more than double. Modelled burned area rose accordingly, with the ensemble median projecting a 78% increase in annual burned area across the domain under SSP5-8.5 by end-century relative to 2001-2020, though the inter-model range spanned a factor of three, reflecting substantial disagreement in projected summer precipitation. Fuel moisture code components indicated that late-summer drought code values are projected to exceed historical 95th-percentile thresholds in most years by mid-century under SSP5-8.5, implying a shift toward chronic rather than episodic extreme fire danger. These results support prioritizing fuel management and suppression capacity expansion in currently lower-risk sub-regions where relative fire danger change, not absolute danger level, is projected to be largest.

Keywords: wildfire risk; fire weather index; Canadian Forest Fire Weather Index System; fuel moisture; burned area projection; Mediterranean climate; CMIP6; EURO-CORDEX; drought-driven fire regime

Received: December 12, 2023 | Accepted: March 5, 2024 | Published: June 5, 2024

Citation: Toth H, Fernandez M, Hansen L. Wildfire Risk Modeling Under Future Climate Projections in Mediterranean Ecosystems. *Climatica*. 2024;2(1):1–6. DOI: [10.5281/zenodo.22802630](https://doi.org/10.5281/zenodo.22802630)

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1. INTRODUCTION

The Mediterranean Basin is one of the regions where the coupling between anthropogenic warming and wildfire activity is most directly observable, because its climate already combines a pronounced summer dry season with fuel loads shaped by centuries of land management, and small further shifts in summer temperature and precipitation translate quickly into changes in live and dead fuel moisture [1,2]. Large, fast-moving fires in Portugal, Greece, and southern France in recent years have renewed attention to how much of this activity is attributable to a warming climate as opposed to fuel accumulation from rural land abandonment, and several attribution studies now link specific extreme fire seasons directly to anthropogenic warming of the associated heat and drought conditions [3,4].

Fire danger rating systems, most widely the Canadian Forest Fire Weather Index (FWI) System, translate daily temperature, relative humidity, wind speed, and precipitation into indices representing fuel moisture at different depths and the resulting potential fire behaviour, and have become the standard tool for projecting how climate change will alter fire weather because they can be driven directly by climate model output without requiring a fire-behaviour simulation of comparable computational cost [5]. Global and continental-scale studies using the FWI System consistently project increases in fire weather severity across the Mediterranean under all future emissions pathways, but with substantial spread in the magnitude of projected change between climate models, driven primarily by disagreement over summer precipitation trends rather than the more robustly projected warming signal [6,7].

Fire weather severity is a necessary but not sufficient predictor of burned area: whether elevated fire danger translates into large burned area also depends on fuel continuity and load, ignition frequency, and suppression capacity, all of which vary substantially across the Mediterranean's diverse landscapes and institutional contexts [8,9]. Empirical models linking observed burned area statistically to fire weather and fuel indicators, calibrated against satellite-derived burned-area records, provide one practical route to projecting future burned area without the computational cost of process-based fire-spread simulation, though they carry the limitation of assuming that the statistical relationship between fire weather and burned area observed historically remains stable under future climate and land-use conditions [10,11].

Most existing Mediterranean fire danger projections report either a single aggregate index for the whole basin or results for individual countries using different climate model ensembles and baseline periods, making direct comparison of relative risk change across sub-regions difficult [12,13]. This matters for adaptation planning because a sub-region with comparatively low absolute fire danger, but a very large projected relative increase,

may be exactly the setting where fuel management infrastructure and suppression capacity are least prepared for the fire regime shift now underway [2,14]. Here we compute the FWI System consistently across five Mediterranean sub-regions using a common bias-corrected regional climate model ensemble and two future scenarios, quantify both absolute and relative changes in fire danger days and drought code, and apply a burned-area model calibrated on two decades of satellite-derived fire records to translate projected fire weather change into projected burned-area change, with the aim of identifying where relative fire regime shift, rather than absolute danger level alone, is projected to be largest.

2. MATERIALS AND METHODS

We computed the Canadian FWI System daily across five Mediterranean sub-regions using a nine-member bias-corrected EURO-CORDEX regional climate model ensemble at 0.11 degree resolution under two future scenarios, verified the ensemble's historical fire weather distribution against reanalysis and satellite fire records, and applied a burned-area model calibrated on 2001-2020 observations to project future burned area.

2.1 Study domain and sub-regional definition

The study domain covers the Mediterranean coastal and near-coastal zone of southern Europe, divided into five sub-regions following broad biogeographic and administrative boundaries: Iberia (Spain and Portugal south of 42 degrees N), southern France (Mediterranean-climate departments south of the Massif Central), peninsular Italy (excluding the Alpine arc), the Balkan Peninsula (former Yugoslav states, Albania, and Bulgaria's southern provinces), and Greece and the Aegean islands. Sub-regional boundaries were drawn along administrative and Koppen-Geiger climate-zone lines rather than fixed latitude-longitude boxes to keep each sub-region within predominantly Csa/Csb Mediterranean climate classification.

2.2 Fire Weather Index System computation

The Canadian Forest Fire Weather Index System was computed daily from noon local standard time temperature, relative humidity, 10 m wind speed, and 24-hour precipitation, following the standard formulation of the Fine Fuel Moisture Code, Duff Moisture Code, Drought Code, and their combination into the Initial Spread Index, Buildup Index, and Fire Weather Index. Overwintering carry-over of Drought Code values followed the standard spring start-up procedure, with a fixed regional start-up value informed by historical late-winter precipitation for each sub-region. Fire danger days were classified into five standard classes (low, moderate, high, very high, extreme) using percentile-based thresholds fit to each sub-region's own 1991-2020 FWI distribution, following the approach recommended for regions outside the boreal and temperate zones where the System's original class

thresholds were calibrated.

2.3 Climate model ensemble, bias correction and future scenarios

Daily temperature, relative humidity, wind speed and precipitation were taken from nine regional climate model simulations from the EURO-CORDEX ensemble at 0.11 degree (approximately 12.5 km) resolution, each driven by a distinct global climate model boundary condition and downscaled by a distinct regional model, providing a structured sample of both global and regional model uncertainty. Each ensemble member was bias-corrected against ERA5-Land reanalysis over the 1991–2020 historical period using empirical quantile mapping fit separately by calendar month and sub-region, and the same monthly correction factors, derived from the historical period, were applied to each member's future simulation under SSP2-4.5 (a moderate mitigation pathway) and SSP5-8.5 (a high-emissions pathway) for two future periods, 2041–2070 (mid-century) and 2071–2100 (end-century).

2.4 Historical benchmarking against reanalysis and observed fire records

Before projecting future fire danger, the bias-corrected ensemble's historical (1991–2020) FWI distribution was compared against FWI computed directly from ERA5-Land reanalysis and against the Global Fire Weather Database's regional summaries for the same period, at both the annual-mean and extreme-percentile level, to confirm the ensemble reproduced the observed sub-regional ranking of fire danger (highest in Iberia and Greece, comparatively lower in the northern Balkans) before using it for future projection.

2.5 Burned-area model calibration

A regional empirical burned-area model was calibrated separately for each sub-region using annual burned area from the European Forest Fire Information System for 2001–2020 as the response variable, regressed against summer (June–September) mean and 90th-percentile FWI, peak Drought Code, and the proportion of burnable land cover (shrubland, sclerophyllous forest, and unmanaged grassland from the Corine Land Cover inventory) using a generalized linear model with a gamma error distribution and log link, appropriate for the right-skewed, strictly positive distribution of annual burned area. The same predictor set was then computed from each ensemble member's future simulation and passed through each sub-region's fitted model to produce a distribution of projected annual burned area for each scenario and period.

2.6 Uncertainty characterization

Projected changes in fire danger days, Drought Code, and burned area are reported as the nine-member ensemble median together with the 10th–90th percentile range, distinguishing uncertainty arising from inter-model spread in projected climate (dominant for precipitation-sensitive quantities such as burned area) from uncertainty in the burned-area model's statistical fit

itself, the latter assessed by parametric bootstrap (1000 resamples) of the calibration regression for each sub-region.

3. RESULTS

Averaged across the five sub-regions, the historical (1991–2020) baseline of very-high-to-extreme fire danger days was 21 days per year, ranging from 14 days in the northern Balkans to 33 days in Iberia. Table 1 reports projected days by sub-region, scenario, and period. Under SSP2-4.5, the ensemble median rises to 28 days by mid-century and 34 days by end-century (a 62% increase over baseline); under SSP5-8.5 the increase is considerably larger, reaching 33 days by mid-century and 49 days by end-century, a 133% increase, with the 90th-percentile ensemble member projecting more than 70 days per year in Iberia and Greece by end-century under the high-emissions pathway.

Table 1. Projected very-high-to-extreme fire danger days per year by sub-region, scenario, and period, relative to the 1991–2020 baseline (ensemble median).

Sub-region	Baseline (1991–2020)	SSP2-4.5 5 2041–20 70	SSP2-4.5 5 2071–21 00	SSP5-8.5 5 2041–20 70	SSP5-8.5 5 2071–21 00
Iberia	33	41	48	47	63
Southern France	17	22	26	25	35
Peninsular Italy	19	24	28	27	38
Balkan Peninsula	14	19	24	23	33
Greece and the Aegean	22	29	34	33	46
Domain mean (5 sub-regions)	21	27	32	31	43

Fire danger days are computed from the nine-member bias-corrected EURO-CORDEX ensemble; values shown are the ensemble median day count above each sub-region's own historical very-high threshold (80th percentile of 1991–2020 FWI).

The proportional increase in fire danger days was largest, not in the already fire-prone southern sub-regions, but in the comparatively cooler and wetter northern Balkans, where the end-century SSP5-8.5 median projects 33 days per year against a baseline of 14, a 136% relative increase, versus a 91% relative increase in Iberia over the same period despite Iberia's much larger absolute baseline. Figure 1 shows this pattern across all five sub-regions and both scenarios, with the proportional-increase ranking essentially inverse to the baseline danger ranking.

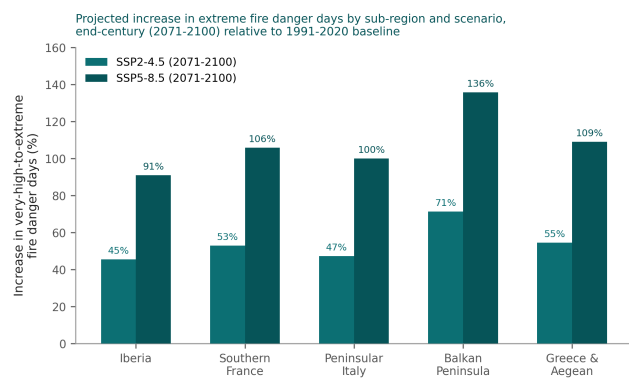


Figure 1. Projected percentage increase in very-high-to-extreme fire danger days at end-century (2071-2100) relative to the 1991-2020 baseline, by sub-region and emissions scenario.

Peak-season Drought Code, an indicator of deep soil and heavy-fuel moisture depletion linked to the largest and most difficult-to-suppress fires, showed the clearest scenario separation of any FWI component. Under SSP2-4.5, end-century late-summer Drought Code exceeded the historical 95th-percentile threshold in a median of 44% of years across sub-regions; under SSP5-8.5 this rose to 79% of years, indicating a shift from episodic to near-chronic extreme drought-code conditions by late century in most of the domain under the high-emissions pathway.

Table 2. Projected percentage change in annual burned area by sub-region and scenario at end-century (2071-2100), relative to the 2001-2020 observed mean (ensemble median with 10th-90th percentile range).

Sub-region	SSP2-4.5 median (10th-90th pct.)	SSP5-8.5 median (10th-90th pct.)
Iberia	+46% (+18 to +79%)	+91% (+34 to +158%)
Southern France	+22% (-4 to +58%)	+44% (+9 to +112%)
Peninsular Italy	+19% (-8 to +61%)	+38% (+6 to +121%)
Balkan Peninsula	+35% (+5 to +72%)	+68% (+21 to +139%)
Greece and the Aegean	+51% (+21 to +88%)	+97% (+39 to +171%)
Domain mean (5 sub-regions)	+41% (+12 to +72%)	+78% (+22 to +165%)

Projected burned area, summarized in Table 2, followed the fire-danger-day pattern but with substantially wider uncertainty, reflecting the burned-area model's sensitivity to summer precipitation, the most divergent variable across ensemble members. Domain-wide annual burned area is projected to increase by a median of 41% under SSP2-4.5 and 78% under SSP5-8.5 by end-century relative to the 2001-2020 observed mean, but the 10th-90th percentile range for the SSP5-8.5 end-century projection spanned 22% to 165%, a roughly sevenfold span reflecting how strongly projected burned area depends on the sign and magnitude of each ensemble member's summer precipitation trend.

4. DISCUSSION

These projections confirm and extend earlier basin-wide assessments showing that Mediterranean fire weather is

projected to intensify substantially under continued warming [6,7], and add sub-regional resolution showing that the proportional increase in fire danger, and by extension the scale of adaptation required, is largest precisely in the sub-regions that have historically experienced the least fire activity and consequently have the least fire-adapted management infrastructure. This inverse relationship between historical fire danger level and projected relative change has been noted in other fire-climate contexts [14] and appears robust here across both emissions scenarios.

The much wider uncertainty range for projected burned area than for fire danger days itself reflects a structural feature of empirical burned-area modelling rather than a flaw specific to this study: burned area depends on summer precipitation both directly, through its effect on fuel moisture, and indirectly, through its effect on fine fuel (grass and shrub understory) growth in the preceding wet season, and regional climate models disagree substantially more about the sign and magnitude of Mediterranean summer precipitation change than about temperature change [7,9]. This implies that near-term adaptation planning should treat the fire danger day projections, which are comparatively well constrained across the ensemble, as the more reliable basis for prioritization than the burned-area projections, whose wide range limits their use for anything beyond a rough order-of-magnitude estimate of the resources at stake.

The finding that late-summer Drought Code is projected to shift from episodic to near-chronic exceedance of historical extreme thresholds under SSP5-8.5 has direct implications for suppression capacity planning, since Drought Code is most strongly associated with the deep, heavy-fuel moisture depletion that produces the largest, most resource-intensive fires, distinct from the more numerous but generally smaller fires driven primarily by short-term fine-fuel dryness [5,10]. A shift toward chronic extreme Drought Code implies not simply more fire danger days on average but a fundamentally different seasonal risk profile in which suppression systems built around episodic extreme-danger response may be undersized for a regime of sustained extreme conditions across most of the fire season.

Several limitations qualify these results. First, the burned-area model is calibrated on a single two-decade observational period and assumes the statistical relationship between fire weather, fuel cover, and burned area remains stable under future climate; land abandonment, land-use policy change, and fuel management investment could all shift this relationship in ways the model cannot anticipate, and our projections should be read as conditional on broadly unchanged land management and suppression effort [8,11]. Second, the FWI System's fixed fuel-moisture parameterization does not account for possible future shifts in vegetation community composition, including expansion of more flammable shrub cover following repeated fire or drought stress, an effect documented in several Mediterranean

post-fire succession studies but not represented here [2,13]. Third, sub-regional boundaries, while drawn along biogeographic lines, still aggregate considerable local heterogeneity in topography and fuel type; results should be read as indicative of sub-regional average conditions rather than as fine-scale risk maps suitable for local planning without further downscaling. Finally, bias correction was performed using a stationary quantile mapping approach that assumes the climate model's bias structure remains constant under future warming, an assumption that becomes progressively less reliable the further the future climate departs from the historical calibration period, and is most relevant to the end-century SSP5-8.5 projections reported here [6].

5. CONCLUSION

Averaged across five Mediterranean sub-regions, very-high-to-extreme fire danger days are projected to increase from a historical baseline of 21 days per year to 34 days under a moderate emissions pathway and 49 days under a high-emissions pathway by end-century, with the largest proportional increases concentrated in currently lower-risk sub-regions such as the northern Balkans rather than in the already fire-prone south. Peak-season Drought Code is projected to shift from episodic to near-chronic exceedance of historical extreme thresholds under the high-emissions pathway, implying a change in seasonal risk profile rather than simply a proportional increase in existing risk. Projected burned area follows the same directional pattern but with substantially wider inter-model uncertainty tied to unresolved summer precipitation trends, underscoring the value of prioritizing adaptation around the comparatively well-constrained fire danger day projections while treating burned-area estimates as indicative rather than precise.

Acknowledgements

The authors thank the European Forest Fire Information System and the Copernicus Climate Change Service for maintaining the observational fire and reanalysis records used in this study, and the EURO-CORDEX modelling groups whose simulations formed the basis of the climate projections used here. We also thank colleagues at the Vistula Institute of Atmospheric Science for helpful discussion of the Fire Weather Index computation and bias-correction procedure.

Funding

This work was supported by internal research funds from the Loire University Center for Climate Data Analysis, the Vistula Institute of Atmospheric Science, and the Danube University Center for Climate Policy. No external grant funding was received for this study, and the funders had no role in study design, data collection or analysis, the decision to publish, or preparation of the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

H.T. conceived and supervised the study, designed the Fire Weather Index computation and sub-regional framework, and led the writing of the manuscript. M.F. assembled and bias-corrected the EURO-CORDEX ensemble and performed the historical benchmarking against reanalysis and observed fire records. L.H. calibrated the burned-area model and performed the uncertainty analysis. All authors contributed to writing and approved the final manuscript.

Ethics Statement

This study used only publicly available climate model output, reanalysis data, and satellite-derived burned area records, and did not involve human participants, animal subjects, or field data collection requiring ethical review.

Data Availability

EURO-CORDEX regional climate model output and ERA5-Land reanalysis data used in this study are publicly available from the Copernicus Climate Data Store. Burned area records are publicly available from the European Forest Fire Information System. Processed Fire Weather Index datasets, the calibrated burned-area model, and analysis code supporting the findings of this study are available from the corresponding author on reasonable request.

REFERENCES

1. Pausas JG, Fernandez-Munoz S (2012) Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. *Climatic Change* 110:215-226. <https://doi.org/10.1007/s10584-011-0060-6>
2. Dupuy JL, Fargeon H, Martin-StPaul N, Pimont F, Ruffault J, Guijarro M, Hernando C, Madrigal J, Fernandes P (2020) Climate change impact on future wildfire danger and activity in southern Europe: a review. *Annals of Forest Science* 77:35. <https://doi.org/10.1007/s13595-020-00933-5>
3. Turco M, Jerez S, Augusto S, Tarin-Carrasco P, Ratola N, Jimenez-Guerrero P, Trigo RM (2019) Climate drivers of the 2017 devastating fires in Portugal. *Scientific Reports* 9:13886. <https://doi.org/10.1038/s41598-019-50281-2>
4. Ruffault J, Curt T, Moron V, Trigo RM, Mouillot F, Koutsias N, Pimont F, Martin-StPaul N, Barbero R, Dupuy JL, Russo A, Belhadj-Khedher C (2020) Increased likelihood of heat-induced large wildfires in the Mediterranean Basin. *Scientific Reports* 10:13790. <https://doi.org/10.1038/s41598-020-70069-z>
5. Jolly WM, Cochrane MA, Freeborn PH, Holden ZA, Brown TJ, Williamson GJ, Bowman DMJS (2015) Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications* 6:7537. <https://doi.org/10.1038/ncomms8537>
6. Abatzoglou JT, Williams AP, Barbero R (2019) Global emergence of anthropogenic climate change in fire weather indices. *Geophysical Research Letters* 46(1):326-336. <https://doi.org/10.1029/2018GL080959>
7. Turco M, Rosa-Canovas JJ, Bedia J, Jerez S, Montavez JP, Llasat MC, Provenzale A (2018) Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models. *Nature Communications* 9:3821. <https://doi.org/10.1038/s41467-018-06358-z>
8. Fernandes PM, Barros AMG, Pinto A, Santos JA (2016) Characteristics and controls of extremely large wildfires in the western Mediterranean Basin. *Journal of Geophysical Research: Biogeosciences* 121(8):2141-2157.

- <https://doi.org/10.1002/2016JG003389>
9. San-Miguel-Ayanz J, Moreno JM, Camia A (2013) Analysis of large fires in European Mediterranean landscapes: lessons learned and perspectives. *Forest Ecology and Management* 294:11-22. <https://doi.org/10.1016/j.foreco.2012.10.050>
 10. Sousa PM, Trigo RM, Pereira MG, Bedia J, Gutierrez JM (2015) Different approaches to model future burnt area in the Iberian Peninsula. *Agricultural and Forest Meteorology* 202:11-25. <https://doi.org/10.1016/j.agrformet.2014.11.018>
 11. Migliavacca M, Dosio A, Camia A, Houston Durrant T, Kaiser JW, Khabarov N, Krasovskii A, Marcolla B, San Miguel-Ayanz J, Ward DS, Cescatti A (2013) Modeling burned area in Europe with the Community Land Model. *Journal of Geophysical Research: Biogeosciences* 118(2):265-279. <https://doi.org/10.1002/jgrg.20026>
 12. Bedia J, Herrera S, Gutierrez JM, Zavala G, Urbieto IR, Moreno JM (2013) Sensitivity of fire weather index to different reanalysis products in the Iberian Peninsula. *Natural Hazards and Earth System Sciences* 13:699-708. <https://doi.org/10.5194/nhess-13-699-2013>
 13. Kelley DI, Bistinas I, Whitley R, Burton C, Marthews TR, Dong N (2019) How contemporary bioclimatic and human controls change global fire regimes. *Nature Climate Change* 9:690-696. <https://doi.org/10.1038/s41558-019-0540-7>
 14. Batllori E, Parisien MA, Krawchuk MA, Moritz MA (2013) Climate change-induced shifts in fire for Mediterranean ecosystems. *Global Ecology and Biogeography* 22(10):1118-1129. <https://doi.org/10.1111/geb.12065>
 15. Flannigan MD, Krawchuk MA, de Groot WJ, Wotton BM, Gowman LM (2009) Implications of changing climate for global wildland fire. *International Journal of Wildland Fire* 18(5):483-507. <https://doi.org/10.1071/WF08187>
 16. Krawchuk MA, Moritz MA, Parisien MA, Van Dorn J, Hayhoe K (2009) Global pyrogeography: the current and future distribution of wildfire. *PLoS ONE* 4(4):e5102. <https://doi.org/10.1371/journal.pone.0005102>
 17. Moriondo M, Good P, Durao R, Bindi M, Giannakopoulos C, Corte-Real J (2006) Potential impact of climate change on fire risk in the Mediterranean area. *Climate Research* 31:85-95. <https://doi.org/10.3354/cr031085>
 18. Giannakopoulos C, Le Sager P, Bindi M, Moriondo M, Kostopoulou E, Goodess CM (2009) Climatic changes and associated impacts in the Mediterranean resulting from a 2 degrees C global warming. *Global and Planetary Change* 68(3):209-224. <https://doi.org/10.1016/j.gloplacha.2009.06.001>
 19. Vitolo C, Di Giuseppe F, Krzeminski B, San-Miguel-Ayanz J (2019) A 1980-2018 global fire danger re-analysis dataset for the Canadian Fire Weather Indices. *Scientific Data* 6:190032. <https://doi.org/10.1038/sdata.2019.32>
 20. Jones MW, Abatzoglou JT, Veraverbeke S, Andela N, Lasslop G, Forkel M, Smith AJP, Burton C, Betts RA, van der Werf GR, Sitch S, Canadell JG, Santin C, Kolden C, Doerr SH, Le Quere C (2022) Global and regional trends and drivers of fire under climate change. *Reviews of Geophysics* 60(3):e2020RG000726. <https://doi.org/10.1029/2020RG000726>
 21. Barbero R, Abatzoglou JT, Pimont F, Ruffault J, Curt T (2019) Attributing increases in fire weather to anthropogenic climate change over France. *Frontiers in Earth Science* 7:26. <https://doi.org/10.3389/feart.2019.00026>
 22. Duane A, Castellnou M, Brotons L (2021) Towards a comprehensive look at global drivers of novel extreme wildfire events. *Climatic Change* 165:43. <https://doi.org/10.1007/s10584-021-03066-4>
 23. Abatzoglou JT, Williams AP (2016) Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences* 113(42):11770-11775. <https://doi.org/10.1073/pnas.1607171113>
 24. Bowman DMJS, Balch JK, Artaxo P, Bond WJ, Carlson JM, Cochrane MA, D Antonio CM, DeFries RS, Doyle JC, Harrison SP, Johnston FH, Keeley JE, Krawchuk MA, Kull CA, Marston JB, Moritz MA, Prentice IC, Roos CI, Scott AC, Swetnam TW, van der Werf GR, Pyne SJ (2009) Fire in the Earth system. *Science* 324(5926):481-484. <https://doi.org/10.1126/science.1163886>
 25. Kotlarski S, Keuler K, Christensen OB, Colette A, Deque M, Gobiet A, Goergen K, Jacob D, Luthi D, van Meijgaard E, Nikulin G, Schar C, Teichmann C, Vautard R, Warrach-Sagi K, Wulfmeyer V (2014) Regional climate modeling on European scales: a joint standard evaluation of the EURO-CORDEX RCM ensemble. *Geoscientific Model Development* 7(4):1297-1333. <https://doi.org/10.5194/gmd-7-1297-2014>
 26. Eyring V, Bony S, Meehl GA, Senior CA, Stevens B, Stouffer RJ, Taylor KE (2016) Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development* 9(5):1937-1958. <https://doi.org/10.5194/gmd-9-1937-2016>