



Research note

UDC: 911.2:614.341(480)

<https://doi.org/10.2298/IJGI1901075M>

Received: March 5, 2019

Reviewed: March 26, 2019

Accepted: March 27, 2019



FOREST FIRES IN FINLAND – THE INFLUENCE OF ATMOSPHERIC OSCILLATIONS

Milan Milenković^{1*}, Vladan Ducić², Jovan Mihajlović², Dragan Burić³, Violeta Babić⁴

¹Geographical Institute "Jovan Cvijic" SASA, Belgrade, Serbia; e-mail: m.milenkovic@gi.sanu.ac.rs

²University of Belgrade, Faculty of Geography, Belgrade, Serbia; e-mails: vladan@gef.bg.ac.rs; millennium@hotmail.com

³University of Montenegro, Faculty of Philosophy, Nikšić, Montenegro; e-mail: buric.d@ucg.ac.me

⁴University of Belgrade, Faculty of Forestry, Belgrade, Serbia; e-mail: violeta.babic@sfb.bg.ac.rs

Abstract: In Finland, in the period 1996–2017, 28,434 forest fires were recorded (an average of 1,292.5 per year), and the total burned area was 11,922 ha (an average of 541.9 ha per year). In both cases, a statistically non-significant downward trend was recorded. Forest fires in Finland do not represent a particularly significant problem, primarily due to climatic characteristics, well-organized fire protection, and low density of population. The research of climate influence included the Atlantic Multidecadal Oscillation (AMO), the North Atlantic Oscillation (NAO), and the Arctic Oscillation (AO). The statistically significant values ($p \leq .05$) of Pearson correlation coefficient were recorded for the August values of NAO and the surface area of burned forest (–0.44), the June values of NAO and the average surface area of forest burned per fire (–0.51) and the May AO values and the average surface area of forest burned per fire (–0.45). For the June values of NAO and the average surface area of forest burned per fire, the Lomb periodogram shows four significant peaks, and the match is at two, at 2.4 and 3.4 years, which supports the hypothesis of the connection between NAO and forest fires in Finland.

Keywords: forest fires; Finland; NAO; AO; Lomb periodogram

Introduction

Finland belongs to the geographical region of Northern Europe and covers an area of 338,455 km² (34,534 km² of water surfaces—lakes, rivers, etc.) with over 5.5 million inhabitants (~18 per km²), most of whom live in its southern part (Statistics Finland, 2019a, 2019b). Finland is the most forested country in Europe (73.11%), and according to the land classification based on its purpose, even 86% of the area is forest land (Finnish Forest Association, 2017a). Most of Finland is in the boreal zone of conifers so that the most common species of trees are Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L.). Among the deciduous species, the most common are silver birch (*Betula pendula* Roth.) and downy birch (*Betula pubescens* Ehrh.). In Finland, forests are mostly mixed. Scots pine is the dominant tree species on 64% of the forest land, spruce on 25%, while birch and other

*Corresponding author, e-mail: m.milenkovic@gi.sanu.ac.rs

deciduous species are dominant on 10% (Finnish Forest Association, 2017b). About 34% of forestry land consists of peatlands, the drying of which creates conditions for the spreading of the areas under forest (Finnish Forest Association, 2016).

According to the data given by San-Miguel-Ayanz et al. (2018), forests in Finland are less endangered by fires in comparison with many European countries. Climatic and biogeographical conditions in Finland do not favor the spread of large wildfires (Vainio, 2001). In this country, anthropogenic influences cause over 70% of fires, while natural causes are below 10% (San-Miguel-Ayanz et al., 2018). Natural causes are primarily lightning strikes, and Larjavaaraa, Pennanena, and Tuomib (2005) claim that positive strikes have a greater significance in this respect.

For the research of fire risks, Finnish Forest Fire Index (Vajda, Venäläinen, Suomi, Junila, & Mäkelä, 2014), as well as Canadian Fire Weather Index (FWI) (Venäläinen et al., 2014) are used. The information for public and fire authorities about forest fire risks is provided by the Finnish Meteorological Institute (2015). The fire season in Finland is April–September (Vajda et al., 2014).

The forest fire protection in Finland is considered well-organized and San Miguel-Ayanz et al. (2018) quote fire fighting means and information campaigns:

- Finnish military forces NH 90 helicopters are available to extinguish forest fires;
- More co-operation between other authorities such as the border guard;
- Continuation of forest fire aerial officer education for fire officers;
- Development of the forest fire index system.

In many studies, forest fires in Finland are associated with climate changes, and there are projections until 2100 (Kilpeläinen, Kellomäki, Strandman, & Venäläinen, 2010; Mäkelä, Laapas, & Venäläinen, 2012; Mäkelä, Venäläinen, Jylhä, Lehtonen, & Gregow, 2014). Lehtonen, Ruosteenoja, Venäläinen, & Gregow (2014) state that by the end of the century, the average annual number of days with an increased fire risk could increase by 10–40%, depending on the applied greenhouse gases (GHG) scenario. Lehtonen, Venäläinen, Kämäräinen, Peltola, & Gregow (2016) have explored large fires and believe that their number could be doubled or even tripled during the century. They also state that large forest fires in Finland occur in May and June as a consequence of human activities, but later in summer, lightning is a more common cause.

The main objective in this paper was to determine the correlation between forest fires in Finland and atmospheric oscillations:

- the Atlantic Multidecadal Oscillation (AMO);
- the North Atlantic Oscillation (NAO);
- the Arctic Oscillation (AO).

The objectives were also the trend analyses of:

- the forest fires in Finland;
- the air temperature in Finland.

Data and methods

The data on forest fires in Finland have been retrieved from the European Commission's report "Forest Fires in Europe, Middle East and North Africa 2017" (San-Miguel-Ayanz et al., 2018) and relate to the period 1996–2017. The data include:

- the total annual number of forest fires;
- the total annual surface area of burned forest;
- the average surface area of forest burned per fire.

The average surface area of forest burned per fire was calculated as a ratio between the total annual surface area of burned forest and the total annual number of forest fires. The monthly and seasonal values of the explored atmospheric oscillations, as well as the data on the air temperature in Finland, have been downloaded from the Internet (Table 1).

Table 1

The sources of data used in the research

Data	Source
AMO ^a	https://www.esrl.noaa.gov/psd/data/correlation/amon.us.long.data
NAO ^b	https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/nao.long.data
AO ^c	https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/ao.long.data
Air temperature ^d	https://climateknowledgeportal.worldbank.org/download-data

Note. ^aNOAA/ESRL Physical Sciences Division (2019a); ^bNOAA/ESRL Physical Sciences Division (2019b); ^cNOAA/ESRL Physical Sciences Division (2019c); ^dWorld Bank Group (2019).

The AMO index is calculated on the basis of a natural variation in the sea surface temperature (SST) in the northern part of the Atlantic Ocean. It has a strong influence on the temperature in the northern part of the Atlantic basin (Europe and North America) (Wang, Lee, & Enfield, 2008). Delworth and Mann (2000) point out that the average cycle is about 70 years, and warm and cold phases from 20 to 40 years.

The NAO index is based on the difference in sea surface air pressure between Island (low) and the Azores (high). It is characterized by positive and negative phases. In northern Europe, strong positive phases are connected with above-normal temperatures and above-normal precipitation over northern Europe. Strong negative phases of the NAO are typically connected with opposite patterns of temperature and precipitation (National Oceanic and Atmospheric Administration, National Center for Environmental Information, 2019a).

The AO index is calculated on the basis of the difference in air pressure between about 45°N (high) and above the Arctic (low). It is also characterized by positive and negative phases. When the AO is in positive phase, there are strong winds circulating around the North Pole. In the negative phase of the AO, winds become weaker and the Arctic air masses penetrate southward more easily (National Oceanic and Atmospheric Administration, National Center for Environmental Information, 2019b).

Linear trends were determined for the given data sets. Statistical significance was determined on the basis of the number of elements ($n-2$) and the determination coefficient (R^2). The research used t -test:

$$t = R[(n - 2)/(1 - R^2)]^{-1}$$

Pearson correlation coefficient (r) on the basis of a linear trend was used for the calculation of the correlation between forest fire data and climate indexes, and statistical significance was tested on $p \leq .05$ and $p \leq .01$. In addition, an analysis of periodicity was done (Lomb periodogram).

Results and discussion

The data set used in the research covers the period of 22 years (1996–2017). In this period, 28,434 forest fires were recorded in Finland (an average of 1,292.5 per year). The largest number of

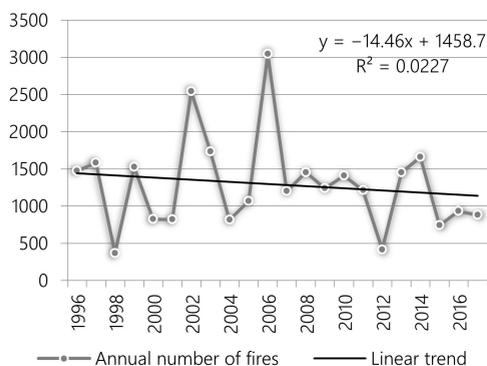


Figure 1. Annual number of forest fires in Finland (1996–2017)

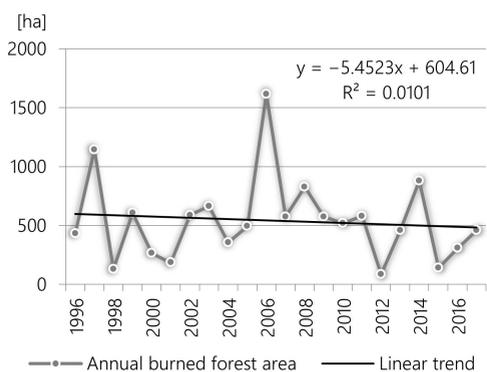


Figure 2. Annual burned forest area in Finland (1996–2017)

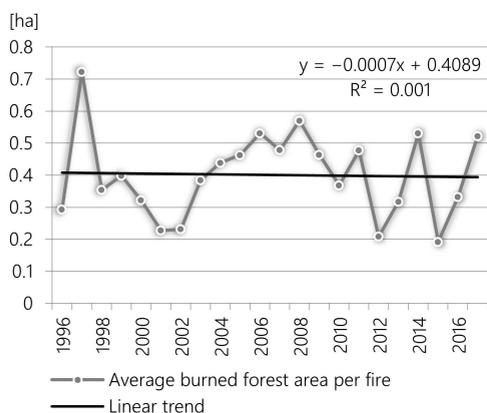


Figure 3. Average burned forest area per fire in Finland (1996–2017)

forest fires was recorded in 2006 (3,046) and the smallest in 1998 (370). A downward trend in the number of fires is not statistically significant (Figure 1).

In the same period, in Finland, the total surface area of burned forest of 11,922 ha (an average of 541.9 ha per year) was recorded. The largest surface area of burned forest was recorded in 2006 (1,617 ha), and the smallest in 2012 (87 ha). The downward trend was recorded and it was not statistically significant (Figure 2). The displayed data relate exclusively to forest land. Thus, in 2017, in Finland, the total burned area was 769 ha, out of which 460 ha was forest land. The average surface area of forest burned per fire was in the range from 0.19 ha (2015) to 0.72 ha (1997), almost without trend (flat trend) (Figure 3).

Based on the data presented, it can be concluded that the fire threat in Finland is relatively smaller compared to many other European countries, especially the countries in the south of Europe (primarily Portugal, Spain, France, Italy, and Greece) (San-Miguel-Ayanz et al., 2018).

The data presented in this paper refer to the period up to 2017. However, in 2018 numerous forest fires were recorded in Finland. In Pyhärinta fire in July, the burned area was close to 100 ha (Ministry of the Interior Finland, 2018). At the same time, in the neighboring Sweden, serious problems with forest fires were also recorded. In the summer 2018, more than 25,000 ha were burnt and almost 3,000,000 m³ of wood were destroyed in the Swedish forests (Johnsen, 2018).

In the research of the climate impact on the forest fires in Finland, the AMO, the NAO, and the AO were considered. In the case of Finland, the basic problem is the lack of data on forest fires, namely their short series. That is why test trials have been carried out to determine whether more significant results can be expected in the future, with an extended database. Tests trials carried out with monthly and seasonal AMO values have not shown

significance. Unlike Finland, the impact of the AMO is significant in France (Milenković, Ducić, Burić, & Lazić, 2016) and Portugal (Milenković, Yamashkin, Ducić, Babić, & Govedar, 2017). In the case of the NAO, statistically significant values of the correlation coefficient were obtained for the August values and the surface area of burned forest (–0.44) and for the June values and the average surface area of forest burned per fire (–0.51), and for the AO for the May values and the average surface area of forest burned per fire (–0.45). In all the three cases, the correlation coefficient values were statistically significant at $p \leq .05$. The connection between the June values of the NAO and the average surface area of forest burned per fire is also indicated by the Lomb periodogram. Four peaks are distinguished, and the match is at two, at 2.4 and 3.4 years.

If trends of the average annual air temperature in Finland are observed, in the period 1996–2015, an increase at a rate of 0.0644 °C per year was recorded (statistically significant at $p \geq .05$). For the spring, an increase at a rate of 0.1143 °C per year was recorded (significant at $p \geq .02$). However, for the summer season, an insignificant negative trend (–0.0041 °C per year) was recorded. When it comes to summer temperatures since 1901, significant variations can be noticed. In the period 1901–2015, the temperature grew at a rate of 0.0089 °C per year (significant at $p \geq .01$). In the 1930s, the warm phase was present, so in the period 1933–2018, an insignificant increase (0.0017 °C per year)—flat trend was recorded. So the warmest decade of 1997–2006 is for only 0.1 °C warmer than the decade 1932–1941.

As far as the longer series are concerned, Mikkonen et al. (2015) established the rise of the mean temperature in Finland in the period 1847–2013 at a rate of 0.14 °C per decade. The authors state that in the period after the 1960s, it grew faster than ever before, and that the rise was the highest for November–January, and the lowest for the summer months. Tietäväinen, Tuomenvirta, & Venäläinen (2010) found, based on gridded temperature data, that for the past 100 years, the rise in the mean temperature was the highest in the spring, and for the last 50 years in the winter period.

Parviainen (1996) states a decrease in the occurrence of forest fires in Finland during the last decades of the 20th century. It is explained by the changes in land use and more efficient fire prevention, as well as by a better control. The same author advocates the application of prescribed burning, which he considers important for biodiversity and the regeneration of forests. Suffling (1992) believes that the increased frequency of the fire would favor the species that inhabit younger forests than those in older forests. In Finland, there is also a well-developed network of forest roads (120,000 km), which provides access for firefighters and presents an obstacle to the rapid spread of fire. In this respect, fragmented forest ownership is also important, and the average size of separate parts of forest is from 2 to 3 ha. In this way, the rapid transfer of crown fires is prevented (Kauppi, 2018).

The expansion of the forest fire database in the future will enable more detailed and more precise research. In the case of Finland, the impact of Northern hemisphere teleconnection patterns on temperature extremes (Irannezhad, Moradkhani, & Kløve, 2018) should be taken into account, and temperature extremes may be linked to forest fires. Research on the impact of the solar activity on forest fires should also be planned, bearing in mind the results obtained by this approach (Milenković, Radovanović, & Ducić, 2011; Radovanović, Vyklyuk, Milenković, Vuković, & Matsiuk, 2015; Radovanović et al., 2015, 2019).

Conclusion

In the investigated period (1996–2017), 28,434 forest fires were recorded in Finland (an average of 1,292.5 per year), while 11,922 ha of forests were burned (an average of 541.9 hectares per year). In both cases, statistically insignificant downward trends were recorded. It has also been found that

forest fires in Finland do not pose a particularly significant problem in comparison to other European countries. The reasons for this are primarily the climate conditions, well-organized forest fire protection and low density of population.

The AMO, the NAO, and the AO were used in the investigation of the connection between the climatic influences and the fire data. Statistically significant values ($p \leq .05$) of the Pearson correlation coefficient (r) were recorded for the August values of the NAO and the surface area of burned forest (-0.44), the June value of the NAO and the average surface area of forest burned per fire (-0.51) and the May AO values and the average surface area of forest burned per fire (-0.45). The Lomb periodogram for June values of the NAO and the average surface area of forest burned per fire shows four significant peaks, and the match is at two, at 2.4 and 3.4 years, which supports the hypothesis of the association of the NAO and forest fires in Finland. The main problem in these surveys was a short data series, so that the results obtained should be taken with a certain doubt.

Acknowledgements

The study is the result of project number 47007 III funded by Ministry of Education, Science and Technological Development of the Republic of Serbia.

References

- Delworth, T. L., & Mann, M. E. (2000). Observed and simulated multidecadal variability in the Northern Hemisphere. *Climate Dynamics*, 16(9), 661–676. <https://doi.org/10.1007/s003820000075>
- Finnish Forest Association. (2016). Finnish forests resources. Retrieved from <https://smy.fi/en/forest-fi/forest-facts/finnish-forests-resources/>
- Finnish Forest Association. (2017a). *Finland and her forests in a nutshell*. Retrieved from https://smy.fi/wp-content/uploads/2017/08/ff_graph_2017_Finland_and_Her_Forests_in_a_Nutshell.pdf
- Finnish Forest Association. (2017b). *Distribution of tree species in Finland*. Retrieved from https://smy.fi/wp-content/uploads/2017/10/ff_Graph_2017_011_Distribution_of_Tree_Species_in_Finland.pdf
- Finnish Meteorological Institute. (2015). The forest fire index [Web page]. Retrieved from <https://en.ilmatieteenlaitos.fi/forest-fire-index>
- Irannezhad, M., Moradkhani, H., & Kløve, B. (2018). Spatiotemporal variability and trends in extreme temperature events in Finland over the recent decades: Influence of Northern Hemisphere teleconnection patterns. *Advances in Meteorology*, 2018, Article ID 7169840, 1–17. <https://doi.org/10.1155/2018/7169840>
- Johnsen, T. (2018). Forest fires in Sweden - huge areas burned in 2018 [Post]. Retrieved from <https://www.forestry.com/editorial/forest-fires-sweden/>
- Kauppi, A. (2018). Finland has a problem with too few forest fires – to promote biodiversity, burned-down areas should be protected [Web page]. Retrieved from <https://smy.fi/en/artikkeli/finland-has-a-problem-with-too-few-forest-fires-to-promote-biodiversity-burned-down-areas-should-be-protected/>
- Kilpeläinen, A., Kellomäki, S., Strandman, H., & Venäläinen, A. (2010). Climate change impacts on forest fire potential in boreal conditions in Finland. *Climatic Change*, 103(3-4), 383–398. <https://doi.org/10.1007/s10584-009-9788-7>
- Larjavaara, M., Pennanena, J., & Tuomib, T. J. (2005). Lightning that ignites forest fires in Finland. *Agricultural and Forest Meteorology*, 132(3–4), 171–180. <https://doi.org/10.1016/j.agrformet.2005.07.005>
- Lehtonen, I., Ruosteenoja, K., Venäläinen, A., & Gregow, H. (2014). The projected 21st century forest-fire risk in Finland under different greenhouse gas scenarios. *Boreal Environment Research*, 19(2), 127–139. Retrieved from <http://www.borenav.net/BER/pdfs/ber19/ber19-127.pdf>
- Lehtonen, I., Venäläinen, A., Kämäräinen, M., Peltola, H., & Gregow, H. (2016). Risk of large-scale fires in boreal forests of Finland under changing climate. *Natural Hazards and Earth System Sciences*, 16(1), 239–253. <https://doi.org/10.5194/nhess-16-239-2016>

- Mäkelä, H. M., Laapas, M., & Venäläinen, A. (2012). Long-term temporal changes in the occurrence of a high forest fire danger in Finland. *Natural Hazards and Earth System Science*, 12(8), 2591–2601. <https://doi.org/10.5194/nhess-12-2591-2012>
- Mäkelä, H. M., Venäläinen, A., Jylhä, K., Lehtonen, I., & Gregow, H. (2014). Probabilistic projections of climatological forest fire danger in Finland. *Climate Research*, 60(1), 73–85. <https://doi.org/10.3354/cr01223>
- Mikkonen, S., Laine, M., Mäkelä, H. M., Gregow, H., Tuomenvirta, H., Lahtinen, M., & Laaksonen, A. (2015). Trends in the average temperature in Finland, 1847–2013. *Stochastic Environmental Research and Risk Assessment*, 29(6), 1521–1529. <https://doi.org/10.1007/s00477-014-0992-2>
- Milenković, M., Ducić, V., Burić, D., & Lazić, B. (2016). The Atlantic Multidecadal Oscillation (AMO) and the forest fires in France in the period 1980–2014. *Journal of the Geographical Institute "Jovan Cvijić" SASA*, 66(1), 35–44. <https://doi.org/10.2298/IJGI1701027M>
- Milenković, M., Radovanović, M., & Ducić, V. (2011). The Impact of Solar activity on the greatest forest fires of Deliblatska peščara (Serbia). *Forum Geografic*, 10(1), 107–116. <https://doi.org/10.5775/fg.2067-4635.2011.026.i>
- Milenković, M., Yamashkin, A. A., Ducić, V., Babić, V., & Govedar, Z. (2017). Forest fires in Portugal — the connection with the Atlantic Multidecadal Oscillation (AMO). *Journal of the Geographical Institute "Jovan Cvijić" SASA*, 67(1), 27–35. <https://doi.org/10.2298/IJGI1701027M>
- National Oceanic and Atmospheric Administration, National Center for Environmental Information. (2019a). North Atlantic Oscillation (NAO) [Web page]. Retrieved from <https://www.ncdc.noaa.gov/teleconnections/nao/>
- National Oceanic and Atmospheric Administration, National Center for Environmental Information. (2019b). Arctic Oscillation (AO) [Web page]. Retrieved from <https://www.ncdc.noaa.gov/teleconnections/ao/>
- NOAA/ESRL Physical Sciences Division (2019a). *Atlantic multidecadal oscillation (AMO) SST Index* [Data set]. Retrieved from <https://www.esrl.noaa.gov/psd/data/correlation/amon.us.long.data>
- NOAA/ESRL Physical Sciences Division (2019b). *North Atlantic Oscillation (NAO)* [Data set]. Retrieved from https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/nao.long.data
- NOAA/ESRL Physical Sciences Division (2019c). *Arctic Oscillation (AO) Index* [Data set]. Retrieved from https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/ao.long.data
- Ministry of the Interior Finland. (2018). *Finland has coped well with fighting forest fires* [Press release]. Retrieved from https://intermin.fi/en/article/-/asset_publisher/poikkeuksellisesta-metsapalokesasta-on-selvitty-hyvin
- Parviainen, J. (1996). Impact of fire on Finnish forests in the past and today. *Silva Fennica*, 30(2–3), 353–359. <https://doi.org/10.14214/sf.a9246>
- Radovanović, M. M., Pavlović, T. M., Stanojević, G. B., Milanović, M. M., Pavlović, M. A., & Radivojević, A. R. (2015). The influence of solar activities on occurrence of the forest fires in South Europe. *Thermal Science*, 19(2), 435–446. <https://doi.org/10.2298/TSCI130930036R>
- Radovanović, M. M., Vyklyuk, Y., Milenković, M., Vuković, D. B., & Matsiuk, N. (2015). Application of ANFIS models for prediction of forest fires in the USA on the basis of solar activity. *Thermal Science*, 19(5), 1649–1661. <https://doi.org/10.2298/TSCI150210093R>
- Radovanović, M. M., Vyklyuk, Y., Stevančević, M., Milenković, M., Jakovljević, D., Petrović, M., . . . Škoda, M. (2019). Forest fires in Portugal – Case study, 18 June 2017. *Thermal Science*, 23(1), 73–86. <https://doi.org/10.2298/TSCI180803251R>
- San-Miguel-Ayanz, J., Durrant, T., Boca, R., Libertà, G., Branco, A., de Rigo, D., . . . Leray, T. (2018). Forest Fires in Europe, Middle East and North Africa 2017 (JRC Publication No. JRC112831) <https://ec.europa.eu/jrc/en/publication/forest-fires-europe-middle-east-and-north-africa-2017>
- Suffling, R. (1992). Climate change and boreal forest fires in Fennoscandia and central Canada. *Catena Supplement*, 22, 111–132. Retrieved from https://www.researchgate.net/publication/313651499_Climate_change_and_boreal_forest_fires_in_Fennoscandia_and_central_Canada
- Statistics Finland. (2019a). Environment and Natural Resources. Geographical data [Web page]. Retrieved from https://www.stat.fi/tup/suoluk/suoluk_alue_en.html
- Statistics Finland. (2019b). Population. Population structure on 31 December [Web page]. Retrieved from https://www.stat.fi/tup/suoluk/suoluk_vaesto_en.html

- Tietäväinen, H., Tuomenvirta, H., & Venäläinen, A. (2010). Annual and seasonal mean temperatures in Finland during the last 160 years based on gridded temperature data. *International Journal of Climatology*, 30(15), 2247–2256. <https://doi.org/10.1002/joc.2046>
- Vainio, T. (2001). The forest fire situation in Finland. *Int. Forest Fire News*, 24, 17–22. Retrieved from <http://www.fao.org/3/AD653E/ad653e73.htm>
- Vajda, A., Venäläinen, A., Suomi, I., Junila, P., & Mäkelä, H. M. (2014). Assessment of forest fire danger in a boreal forest environment: Description and evaluation of the operational system applied in Finland. *Meteorological Applications*, 21(4), 879–887. <https://doi.org/10.1002/met.1425>
- Venäläinen, A., Korhonen, N., Hyvärinen, O., Koutsias, N., Xystrakis, F., Urbiet, I. R., & Moreno, J. M. (2014). Temporal variations and change in forest fire danger in Europe for 1960–2012. *Natural Hazards and Earth System Sciences*, 14(6), 1477–1490. <https://doi.org/10.5194/nhess-14-1477-2014>
- Wang, C., Lee, S.-K., & Enfield, D. B. (2008). Atlantic Warm Pool acting as a link between Atlantic Multidecadal Oscillation and Atlantic tropical cyclone activity. *Geochemistry, Geophysics, Geosystems*, 9(5), Q05V03. <https://doi.org/10.1029/2007GC001809>
- World Bank Group. (2019). Download Data [Web page]. Retrieved from <https://climateknowledgeportal.worldbank.org/download-data>