2023

Forest Condition in Europe

The 2023 Assessment

ICP Forests Technical Report under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention)

LRTAP Long-range Transboundary Air Pollution

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Alexa Michel, Till Kirchner, Anne-Katrin Prescher, and Kai Schwärzel (editors)

United Nations Economic Commission for Europe (UNECE)
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http://icp-forests.net

Contact

Programme Co-ordinating Centre of ICP Forests
Kai Schwärzel, Head
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde, Germany
Email: pcc-icpforests@thuenen.de

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6

METEOROLOGICAL CONDITIONS IN EUROPEAN FORESTS IN 2021

Lothar Zimmermann, Stephan Raspe, Char Hilgers, Kai Schwärzel, Alexa Michel

Introduction

Weather and climate affect composition, structure, growth, health, and dynamics of forest ecosystems (Geiger 1961; Baumgartner 1967a, b; Lee 1978, 1980; Mitscherlich 1981; Swank and Crossley 1988; Chang 2006). Observing weather conditions and their seasonal variations on forest monitoring plots is therefore essential for identifying and interpreting trends in forest condition. Furthermore, weather data are needed to identify and understand interactions with other stressors such as air pollution, diseases, or pests. Against this background, the ICP Forests Level II plots were equipped with meteorological measurement devices as early as the 1990s. The resulting Europe-wide network of forest meteorological stations provides site-specific forest meteorological data including air temperature, relative humidity, precipitation, wind speed and direction, global radiation, and soil moisture and temperature. In combination with data from other ICP Forests surveys (e.g. tree growth, crown condition, phenology, ground vegetation, soil), these data can be used to analyze the effect of the atmospheric environment and its change over time on vitality and development of forest ecosystems.

For a better understanding of the effects of the atmosphere on forests, data interpretation should always be aimed at improving the process-based understanding of soil-forest-atmosphere interactions. Mayer and Schmidt (1991) identified atmospheric stress factors as e.g. late frost or heat periods, which are potentially relevant for states of and processes in forests.

The main objectives of the meteorological monitoring at the Level II plots are:

- to describe the meteorological conditions and changes at the Level II plots;
- to investigate the meteorological conditions and contribute to the explanation of and the relationship with the state of the ecosystem;
- to identify and investigate stress indices and factors for trees on the plot like extreme weather conditions and events (e.g. frost, heat, drought, storms, floods);
- to build-up long time-series that fulfil requirements of further analysis (statistics and modelling) of ecosystem responses under current and changing environmental conditions (e.g. water balance calculations, soil water availability for the stand, growth, nutrient cycling) as well as integrated evaluations in various aspects of the Level II plots (e. g. crown condition assessment, deposition, increment) (Raspe et al. 2020).

Temperature and precipitation patterns play a key role in climate change impacts on forests (Kirilenko and Sedjo 2007). This chapter, therefore, focuses first on presenting and interpreting air temperature and precipitation data from 2021 in comparison with long-term average values (1990–2020) for different climatic regions in Europe. Level II meteorological stations were allocated to climatic regions according to the well-known Koeppen-Geiger climate classification scheme with the aim to aggregate values from Level II plots and show changes across European climatic regions. The classification comprises here four main classes and 10 sub-types (Beck et al. 2018). It is based on threshold values and seasonality of monthly air temperature and precipitation. Considering vegetation as "crystallized, visible climate", this classification aims to empirically map biome distributions around the world: different regions in a similar climate class share common vegetation characteristics (Beck et al. 2018). The most frequent Koeppen climatic regions in Europe are (1) C-climates, which are temperate climates e.g. CfB atlantic temperate (beech climate) up to warm to hot Mediterranean climate (Csb, Csa), and (2) D-climates, which are continental climates from humid continental (Dfa, Dfb: oak climate) to subarctic (Dfc: birch climate) and also to Mediterranean-influenced warm-summer humid continental climate (Dsa) (Tab. 6-1). The distribution of the Level II meteorological stations across Europe is shown in Figure 6.1. The allocation to climatic regions results in a large difference in the number of stations in the individual categories. Therefore, the informative value of individual subgroups is partially limited.

Climate and weather in Europe 2021

Weather conditions in 2021 in Europe were much cooler than in most recent years, but still warmer than for the reference period (1991–2020). In early spring, many parts of Europe saw a transition from unusually warm to unusually cold temperatures, with frost-related impacts. Summer was the warmest on record and brought also several extreme events. In July, above-average soil moisture, a slow-moving low-pressure system, and record precipitation across Belgium, Germany, and eastern France resulted in extreme flooding. A long-lived and intense heatwave in the Mediterranean, combined with very dry conditions, led to high levels of heat stress and intense wildfires. Although summer was the warmest on record, with + 1.0 °C above average, spring was less than 0.5 °C cooler than average. For the year as a whole, the most-above-average temperatures were found around the Black Sea, in southeastern Europe, and in western Russia. Temperatures in Scandinavia, and to a lesser extent in central Europe, were cooler than average. (EU-Copernicus-ECMWF 2022).

Table 6-1: Number of meteorological stations (n) at Level II plots in different climatic regions in 2021. For criteria, please refer to Table 3 in Beck et al. 2018.

Code	Description of climate	Name	n
BSk	Arid, steppe, cold	Cold semi-arid climate	7
Cfa	Temperate, no dry season, hot summer	Humid subtropical climate	5
Cfb	Temperate, no dry season, warm summer	Temperate oceanic climate	36
Csa	Temperate, dry summer, hot summer	Hot-summer Mediterranean climate	5
Csb	Temperate, dry summer, warm summer	Warm-summer Mediterranean climate	4
Dfa	Cold, no dry season, hot summer	Hot-summer humid continental climate	1
Dfb	Cold, no dry season, warm summer	Warm-summer humid continental climate	135
Dfc	Cold, no dry season, cold summer	Subarctic climate	22
Dsb	Cold, dry summer, warm summer	Mediterranean-influenced warm-summer humid	1
ET	Polar, tundra	Tundra climate	1
		TOTAL	217

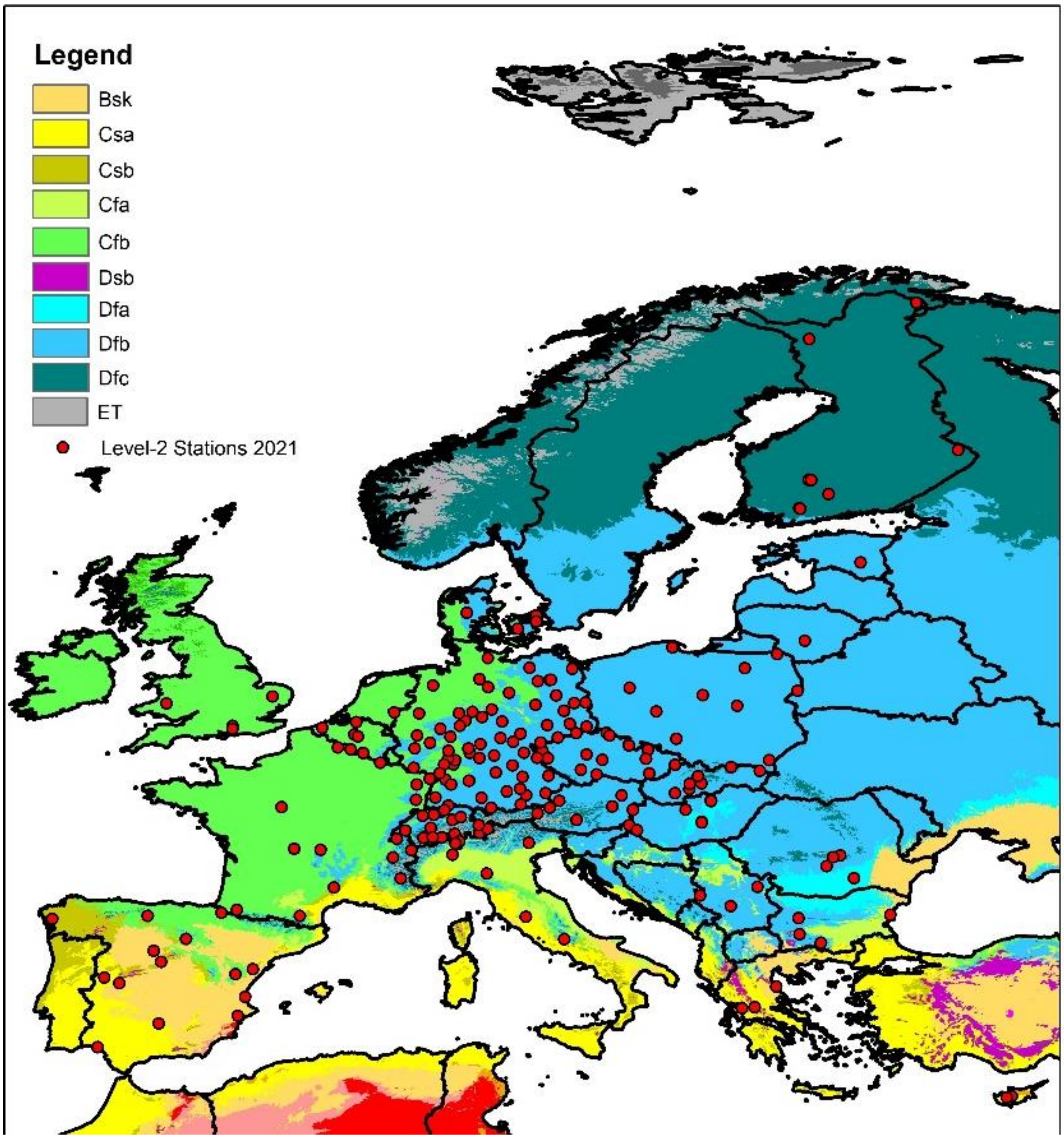

Figure 6-1: Map of Level II stations with gap-filled time series of meteorological data for 2021 and for different climatic regions (Table 6-1 acc. to Beck et al. 2018).

Materials and methods

Meteorological monitoring in the ICP Forests program includes measurements of standard surface meteorological variables according to international recommendations by the World Meteorological Organization (WMO 2008). In order to represent the specific climatic conditions of a forest, while being aware of potential errors due to the large spatial variability of meteorological data, all meteorological measurements were taken at an open field station within the forest area in close proximity to a Level II plot or from a weather station nearby.

Technical equipment, sensors and their placement are in accordance with WMO standards (WMO - No. 8, No. 100, No. 168) and are compatible with national weather service networks. For details on the recorded parameters, the measurement design, data handling, as well as on quality assurance and quality control standards within the ICP Forests program, please refer to Raspe et al. (2013 and 2020). In this chapter, we only present air temperature and precipitation data in 2021 and compare it with their long-term average (1990–2020).

Air temperature sensors are installed in a passively ventilated solar radiation shield for accurate ambient measurements. Mast-mounted sensors are positioned at a height of 2 m above ground level, on the north side of the mast. Only stations with a measurement height between 1.2 and 3.0 m were included in the analysis. Precipitation was measured with a tipping bucket or weighing rain gauges 1 m above the ground located in a relatively flat, open area. The orifice of the gauge is a horizontal plane, open to the sky.

Meteorological measurements are made quasi-continuously and are then aggregated to daily values (means or sums) with a minimum requirement on the completeness of 95% for air temperature and 100% for precipitation.

Data were cleaned according to ranges of plausible values as given in the ICP Forests Manual (Raspe et al. 2020) and checked for duplicates. Missing values in daily air temperature and the daily sum of precipitation were filled by adjusting modelled values from the ERA5-Land data set from the Copernicus Climate Change Service – Climate Data Store (Copernicus Climate Change Service (C3S) 2017). ERA5-Land is a climate reanalysis model at a resolution of 9 km. It is available on an hourly basis for many climate variables, but because the 9 km grid is much coarser than ICP Forests' near-plot observations, we applied some adjustments to the modelled ERA5-Land values.

For air temperature, we applied a linear regression for each plot, finding a slope and intercept that related ICP Forests' non-missing observations on the forest plot (for all years of observation) to the modelled ERA5-Land values on their 9 km grid. This worked well for altitude differences. For 183 plots on which air temperature was measured in 2021, 52% of plots had at least one missing value that required gap filling, but overall only 7% of daily values were filled per plot on average. Statistics in Table 6-2 indicate good agreement for air temperature.

Table 6-2: Statistics of the deviation between observed daily values and the adjusted ERA5 values

Parameter	Mean difference	Absolute difference	Median difference
Air temperature	0.00 °C	0.96 °C	0.00 °C
Precipitation	0.01 mm	2.04 mm	-0.02 mm

Precipitation is a notoriously difficult variable to fill for a particular location, because of large variation in precipitation amounts over relatively small distances. Where available, we used precipitation amounts collected in the ICP Forests deposition survey. These are generally collected as the sum of precipitation over a two-week period. To then find a daily precipitation amount, we distributed the sum of precipitation found in the deposition survey according to the daily precipitation amount in ERA5-Land. Where deposition data was unavailable, we used the ERA5-Land amount directly. For 204 plots on which precipitation was measured in 2021, 46% of plots had missing values during the year that required gap filling and this resulted in only 7% of values filled per plot on average. Statistics in Table 6-2 indicate fairly good agreement for precipitation.

In order to be able to classify the weather conditions in 2021, the measurement data from 2021 were compared with the long-term average of the climatological normal period 1990–2020. For this purpose, the time series of the individual measuring stations were partially extended backwards to 1990 with the help of the ERA5-Land data set.

Results

Air temperature

Mean annual air temperature

In general, mean air temperatures of ICP Forests Level II plots show differences between stations, with high annual temperatures in the Mediterranean region, moderate temperatures in central Europe and colder temperatures in northern Europe (Fig. 6-2). Extreme low values could be found in northern Finland and at higher situated plots in the Alps. Figure 6-2 also shows that the year 2021 was warmer than normal in southern, southeast and a few other plots across Europe and cooler in west-central and western Europe.

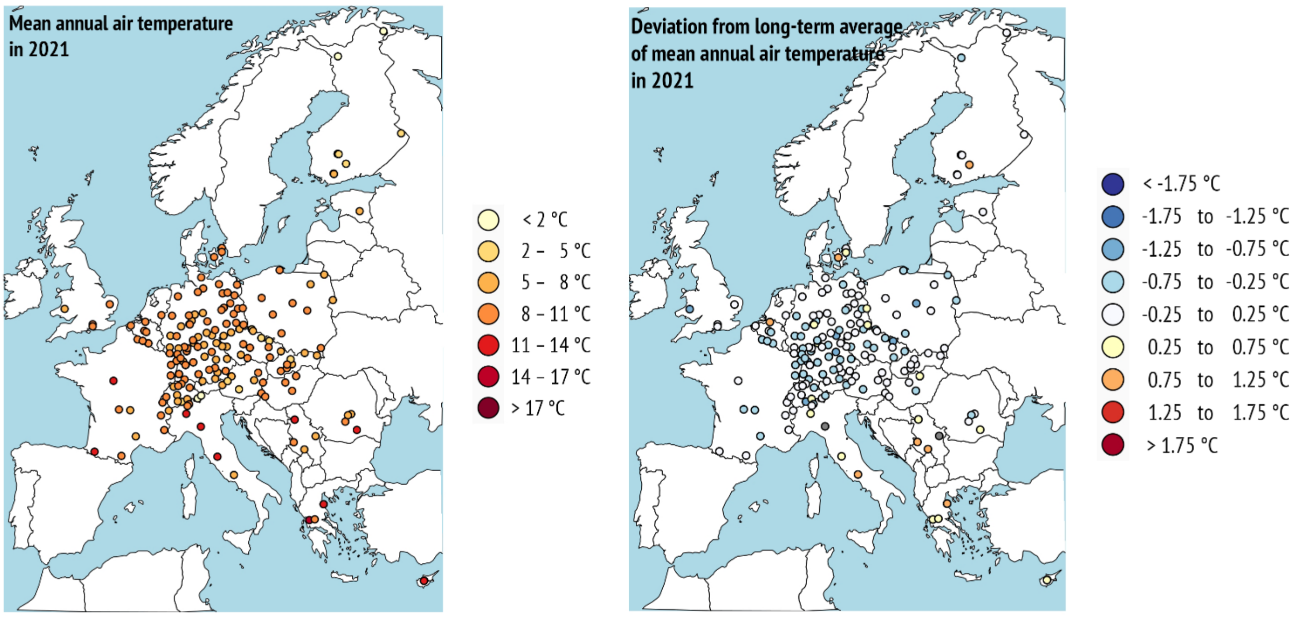

Figure 6-2: Mean annual air temperature (°C) in 2021 (left) and deviation of annual air temperature (°C) in 2021 from the long-term average (1990–2020) on Level II plots.

Mean air temperature in the vegetation period

For air temperature in the vegetation period (Fig. 6-3), we see a more continental influence on Level II plots in east-central Europe starting in north-east Germany and increasing eastwards. High temperatures occur in southern and SE-Europe, low temperatures in western, west-central Europe and in the Alps. In contrast to the year as a whole, it was significantly warmer than the long-term average during the vegetation period in most of Europe, with only some plots showing negative deviations. In western-central and western Europe and also at same sites in southern Europe (Greece) and east-central Europe (e.g. Hungary, Serbia), the temperature was slightly colder than the long-term average, although some plots in these regions also show positive temperature deviations (Fig. 6-3).

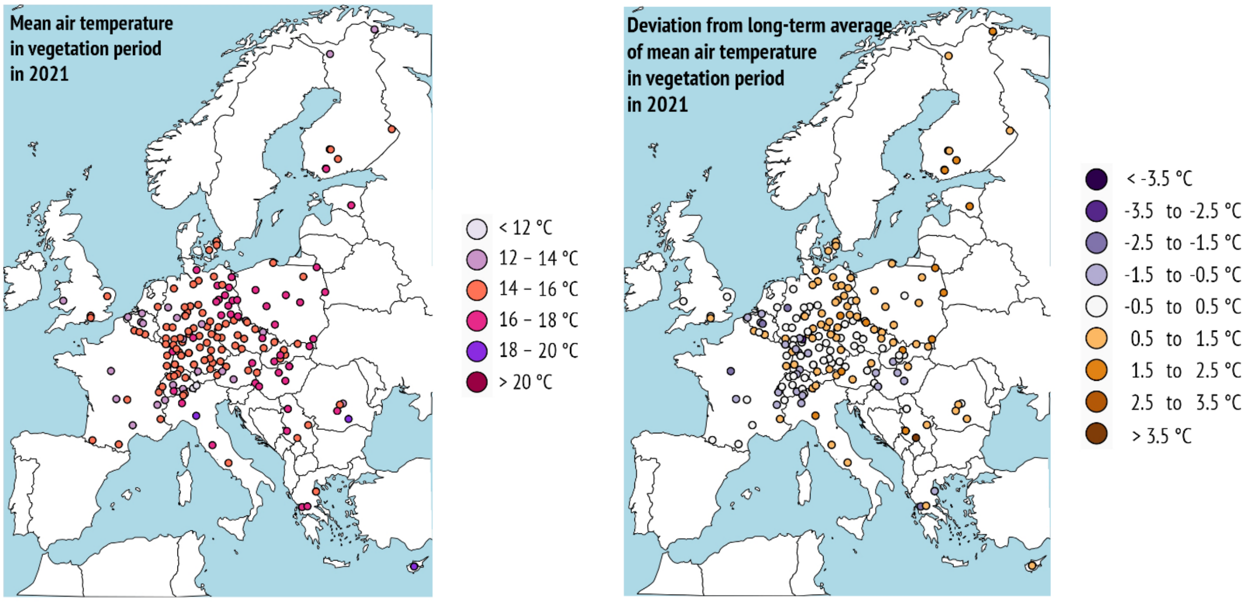

Figure 6-3: Mean air temperature (°C) in the vegetation period in 2021 (left) and deviation of mean air temperature (°C) in the vegetation period in 2021 from the long-term average (1990–2020, right) on Level II plots.

Annual mean air temperature in different climatic regions

To complement the picture of annual mean air temperature at Level II plots during the year 2021, averages for different climatic regions were calculated. For the majority of Level II plots in continental climates (Dfa, Dfb, Dfc, Dsb) as well as in the temperate oceanic climate (Cfb), air temperature was near normal, while Mediterranean climates (Csa and Csb), the humid subtropical climate (Cfa) and cold semi-arid climate (Bsk) showed significant warmer conditions in 2021 than the long-term average (Fig. 6-4). However, it must be noted that the number of Level II plots varies greatly in the different climatic regions (Table 6-1).

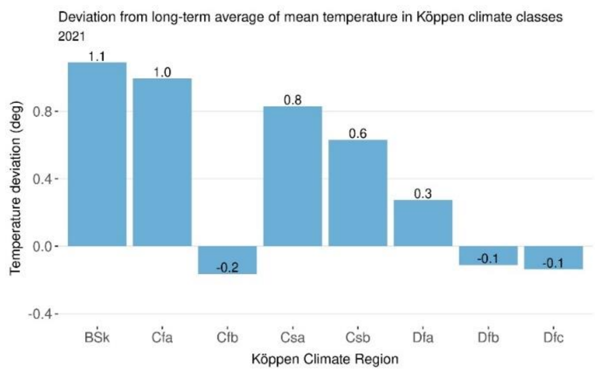

Figure 6-4: Deviation of annual mean air temperature in 2021 from the long-term average (1990–2020) on Level II plots in different Koeppen climatic regions. For explanation of acronyms and for number of Level II plots in each climatic region, please refer to Table 6-1 and Figure 6-1).

Temperature stress indicators

The health and vitality of forests are affected more by extreme temperatures than by mean values. Heat and frost events are of special interest in this respect.

Heat

In 2021, maximum temperatures above 36 °C during the vegetation period occurred at Level II plots in southern and SE-Europe, but also on one Level II plot in Hungary and a few in Germany. The majority of Level II plots in central Europe showed maximum temperatures during the vegetation period between 24 °C and 36 °C (Fig. 6-5). Forests all across southern Europe were confronted by unusual hot days in 2021. Above long-term average maximum air temperatures in the vegetation period, partly up to +3.5 °C and more were found in southern and south-eastern Europe due to a pronounced heat wave (Fig. 6-5). But also in Finland, northeast Germany, and the United Kingdom the maximum air temperature in 2021 was significantly higher compared to the long-term average. In contrast, Belgium, Switzerland, Czechia, some regions of France, and large parts of Germany were significantly cooler compared to the long-term average, with a very pronounced negative deviation of up to -3.5 °C and more on some Level II plots (Fig. 6-5).

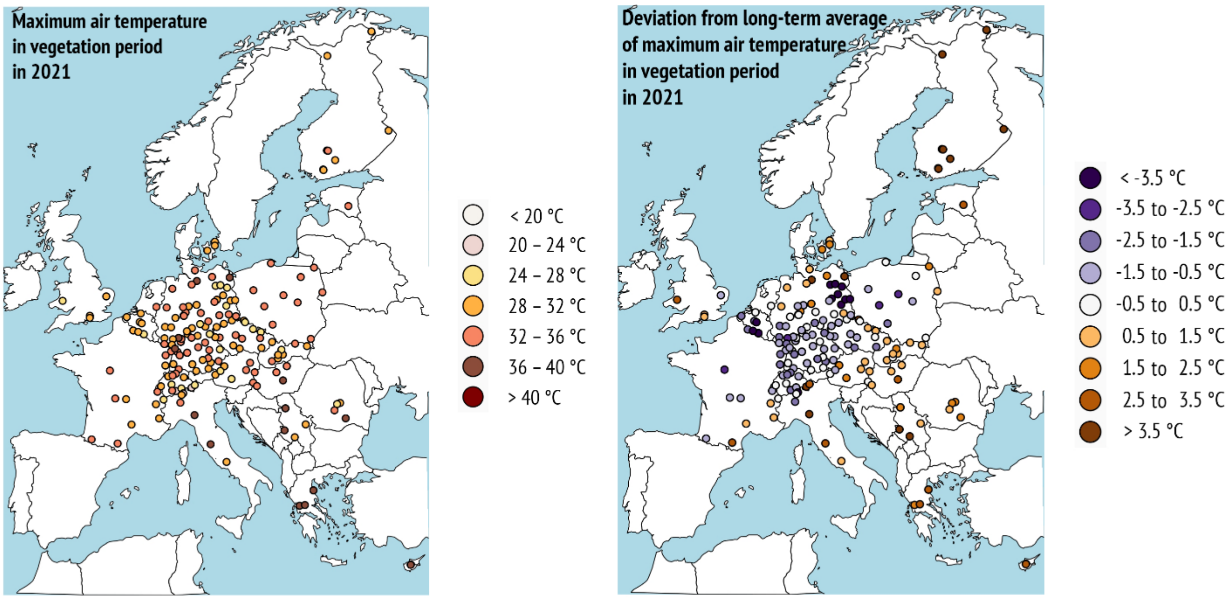

Figure 6-5: Maximum air temperature (°C) in the vegetation period in 2021 (left) and deviation of the maximum air temperature (°C) in the vegetation period in 2021 from the long-term average (1990–2020) (right) on Level II plots.

Another indicator of the risk of heat stress on forests is the number of hot days with a temperature maximum above 30 °C. For the majority of Level II plots in a humid continental climate (Dfa, Dfb), there was no increase in extreme hot days compared to the long-term average, only the one station with Dfa-climate showed a marked increase of nearly more than 20 hot days. An increase of around 10 hot days compared to the long-term average occurred in the cold semi-arid steppe climate (Bsk), the humid subtropical climate (Cfa), and the Mediterranean climates (Csa, Csb) (Fig. 6-6).

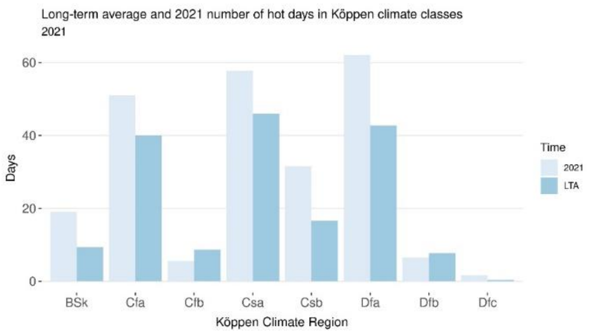

Figure 6-6: Number of hot days (Tmax ≥ 30 °C) in 2021 and long-term yearly average (1990–2020) on Level II plots in different Koeppen climatic regions. For explanation of acronyms and for number of stations in each climatic region, please refer to Table 6-1 and Figure 6-1.

Late frost

Late frost occurs when the daily minimum temperature falls below 0 °C after the start of the vegetation period. This can cause damage to the young shoots or flowers of trees, especially shortly after bud break. The number of frost days in the growing season can be therefore considered as an indicator of late frost stress.

In 2021, an exceptional deviation from normal was observed on Level II plots with humid subtropical climate (Cfa), temperate oceanic climate (Cfb), and cold semi-arid climate (Bsk); instead of 1 to 2 frost days, up to 7 frost days were observed on these plots in 2021 compared to the long-term average (Fig. 6-6).

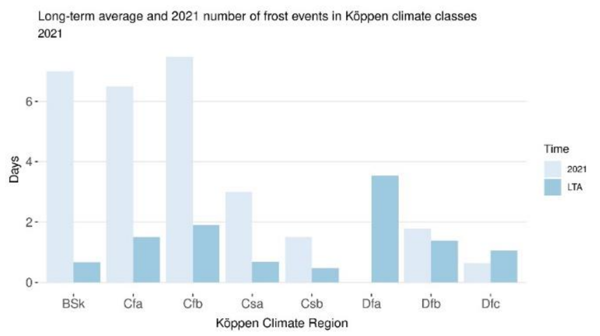

Fig. 6-7: Number of late frost days (Tmin in vegetation period < 0 °C) in 2021 and long-term yearly average (1990–2020) on Level II plots in different Koeppen climatic regions. For explanation of acronyms and for number of stations in each climatic region, please refer to Table 6-1 and Figure 6-1.

Precipitation

Annual precipitation

The distribution of total annual precipitation in 2021 on Level II plots shows a more or less normal pattern. The highest annual precipitation was found in the Alps and mountain stations in Greece and the lowest in Spain as well as in east-central and south-eastern Europe (Fig. 6-8).

The deviation of total precipitation in 2021 from the long-term average (1990–2020) is less than 45% in either direction on the majority of plots and seldom reaches higher values. Towards the Mediterranean Sea, especially in Serbia, northern Italy, and Spain higher negative deviations were found. In general, the year 2021 was slightly drier than normal all across Europe (Fig. 6-8). However, exceptions can be found, e.g., in Greece, Bulgaria, Spain, north-eastern Germany, and in the mountain regions on the German-Czech, Czech-Polish, and Slovak-Polish borders.

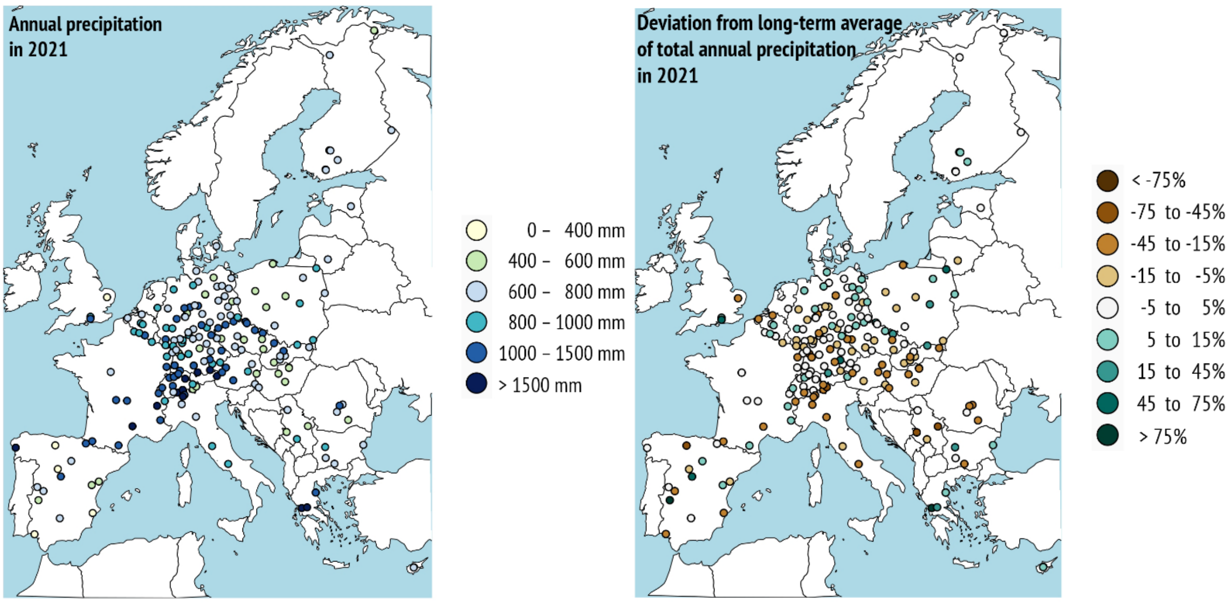

Fig. 6-8: Annual precipitation in mm (l/m²) in 2021 (left) and deviation of the total annual precipitation in 2021 from the long-term yearly average (1990–2020) (in %, right) on Level II plots.

This is also evident from the mean precipitation amounts in the different European climatic regions. For the majority of Level II plots in continental climates and temperate climates without dry seasons, precipitation was significantly (Dfa, Cfa) or slightly (Dfb, Dfc, Cfb) lower than normal, while in Mediterranean climates it was significantly (Dsb) or slightly wetter (Csa, Csb) than the long-term average (Fig. 6-9).

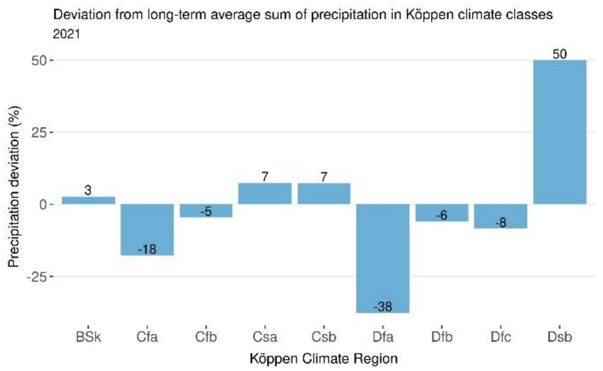

Fig. 6-9: Deviation from the long-term average of the annual precipitation on Level II plots in different Koeppen climatic regions. For an explanation of acronyms and for number of stations in each climatic region, please refer to Table 6-1 and Figure 6-1.

Precipitation in the vegetation period

The amount of precipitation during the growing season is of particular importance for the water supply of forests. In 2021, very low values below 150 mm were found on Level II plots in northern Finland, northern Spain, and Cyprus. The highest values were measured in the Alps and the Greek mountains (Fig. 6-10).

Regarding the deviation of the precipitation in the vegetation period in 2021 from the long-term average, the majority of Level II plots in Belgium, western Germany, and Switzerland show positive deviations likely due to the exceptional flood-producing rainfall in July. The largest part of central and SE-Europe show more negative deviations except for two plots in Greece, while Spain gives a mixed picture. In general, a heterogeneous picture may result from small-scale variations of summer thunderstorms. In the Swiss Alps, more than 75% more precipitation was measured in 2021 compared to the long-term average. South of the Alps in Italy and in SE-Europe, however, Level II plots were exclusively drier than normal during the vegetation period in 2021. One plot in Serbia was especially extremely dry (Fig. 6-10).

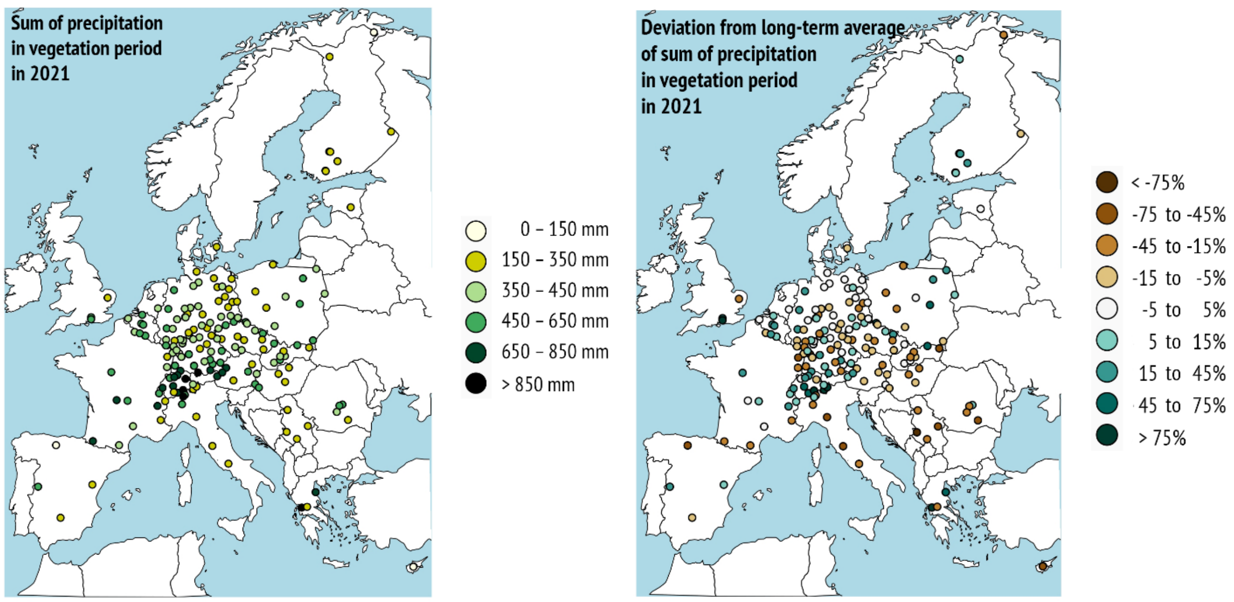

Figure 6-10: Precipitation (in mm (l/m^2)) in the vegetation period in 2021 and deviation (in %) of the precipitation in the vegetation period in 2021 from the long-term average (1990–2020) on Level II plots.

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