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EMEP

Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe

Ozone measurements 2019

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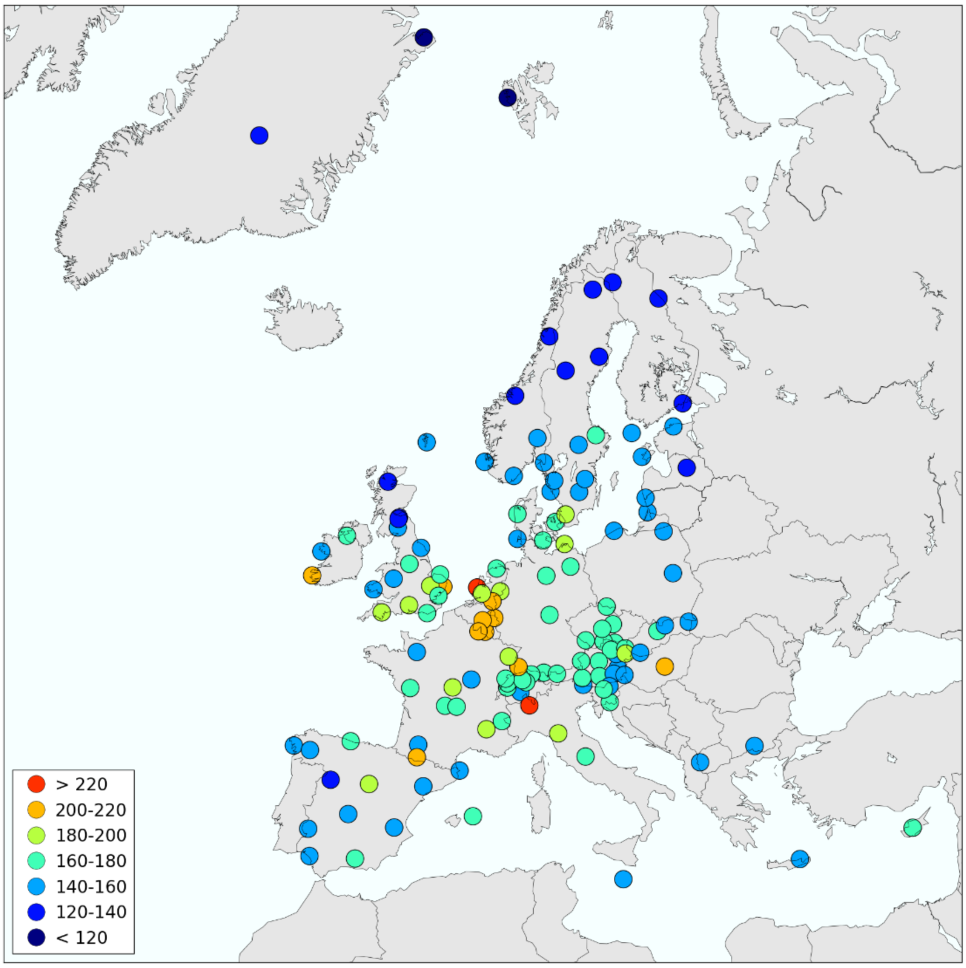

Maximum ozone concentration 2019 µg/m³

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1. Introduction

Ozone is a natural constituent of the atmosphere and plays a vital role in many atmospheric processes. However, man-made emissions of volatile organic compounds and nitrogen oxides have increased the photochemical formation of ozone in the troposphere. Until the end of the 1960s, the problem was basically believed to be one of the big cities and their immediate surroundings. In the 1970s, however, it was found that the problem of photochemical oxidant formation is much more widespread. The ongoing monitoring of ozone at rural sites throughout Europe shows that episodes of high concentrations of ground-level ozone occur over most parts of the continent every summer. During such episodes, the ozone concentrations can reach values above ambient air quality standards over large regions and lead to adverse effects for human health and vegetation. Historical records of ozone measurements in Europe and North America indicate that in the last part of the nineteenth century the values were only about half of the average surface ozone concentrations measured in the same regions during the last 10-15 years (Bojkov, 1986; Volz and Kley, 1988).

The formation of ozone is due to a large number of photochemical reactions taking place in the atmosphere and depends on the temperature, humidity and solar radiation as well as the emissions of nitrogen oxides and volatile organic compounds. Together with the non-linear relationships between the primary emissions and the ozone formation, these effects complicate the abatement strategies for ground-level ozone and makes photochemical models crucial in addition to the monitoring data.

The EMEP ozone data from 2019 is presented in this report, which aims to give a short summary of the measurement data. A complete set of data can be downloaded from the web at http://ebas.nilu.no.

2. Critical levels

Ozone concentrations vary widely from region to region, with the time of year, and with time of day. Typically, high concentrations of ozone are observed in periods with anticyclonic conditions. Such episodes may lead to adverse environmental effects such as impact on human health, agricultural crops, forests and materials. National authorities and international organisations have therefore defined threshold levels for ozone. Within WHO, these are called “air quality guidelines”, within EU “target value”, “long-term objective” etc. and within UN-ECE “critical levels”. The values of the various threshold levels vary among these organisations and, additionally, the health-based indicators are normally based on concentration ($\mu g/m^3$), whereas those related to vegetation are based on mixing ratio (ppb). An overview of various levels relevant for vegetation and human health is given in Table 1 and Table 2, respectively.

Table 1: Limit values for the protection of vegetation.

AOT40 (ppb hours)	Period	Reference	Comment
3000	3 months	CLRTAP (2011)	Critical level for crops and natural vegetation [1)]
5000	1 April - 1 Oct	CLRTAP (2011)	Critical level for forest [1)]
6000	3.5 months	CLRTAP (2011)	Critical level for horticultural crops
9000	1 May – 1 Aug	EU (2008)	EU's target value for vegetation [2,3)]
3000	1 May - 1 Aug	EU (2008)	EU's long-term objective for vegetation [2,3)]

1) ECE's AOT values should be based on the hours with global incoming radiation > 50 W/m^2
2) EU's AOT values should be based on the period 08-20 CET
3) The EU directive uses µg/m^3 and a factor 2 µg/m^3 = 1 ppb

Table 2: Limit values for the protection of human health.

Value (µg/m^3)	Averaging time (hours)	Ref	Description
180	1	EU (2008)	EU's information threshold
240	1	EU (2008)	EU's alert threshold
120	8[1)]	EU (2008)	EU's target value. 8-hour mean value not to be exceeded on more than 25 days per year averaged over 3 years.
120	8[1)]	EU (2008)	EU's long-term objective.
100	8[1)]	WHO (2006)	WHO's air quality guideline (global update 2005)

[1)] The highest 8-hour running mean value for each day calculated such that the 8-hour periods are assigned to the day on which the period ends.

Within UN-ECE, scientific evidence has suggested that AOT40 based critical levels for vegetation (Gothenburg Protocol of 1999) should be replaced by stomatal flux-based critical levels. Flux-based critical levels have been developed to reflect that the real impacts depend on the amount of the pollutant transported into the leaves, whereas AOT40 is only based on the concentration of ozone in the atmosphere at the top of the plant canopy (Mills et al., 2011). Concentration-based critical levels (AOT_x) for estimating the risk of damage to vegetation are, however, still included where climatic data or suitable flux models are not available.

The concentration-based critical level is 3000 ppbh (3-months period) for agricultural crops and (semi-)natural vegetation and 5000 ppbh (6-months period) for forest trees. The former critical level for forest was 10 000 ppbh, and the new, lower level is seen as a clear improvement (CLRTAP, 2011). The "Modelling and mapping manual" strongly recommends that the critical levels should be based on the concentrations at the canopy-height, whereas the measurements normally are taken at 2 m height above ground. When meteorological measurements are not available, it is recommended to adjust the measured data to values relevant for the canopy-height by applying a given vertical profile depending on the type of vegetation.

Furthermore, the period for calculation of AOT40 should reflect the true growing season and should thus be adapted to the climate of the various regions in Europe, as specified in the Mapping Manual (CLRTAP, 2011). This leads to large differences in the applied period, from March-May in East Mediterranean to June-August in North Europe, which in turn has major consequences for the calculated AOT values. Since the aim of the present report is to document the general status of the ozone levels and not to provide any effect-based calculations, the same 3-months period (May-July) is used for all stations. This also corresponds to the period stated in the EU directive. Moreover, no adjustment of the measured values to take the canopy-height into account is done in this report. The measurement data are used directly.

EU has in the ozone directive (2002/3/EC) and the ambient air quality directive (2008/50/EC), defined a number of target values and long-term objectives for the protection of vegetation and human health. The target value for human health is 120 $\mu g/m^3$ (8h mean) which is not to be exceeded on more than 25 days per year averaged over 3 years. For protection of vegetation, AOT40 (May-July) should not exceed 18 000 $\mu g/m^3h$ averaged over five years. In addition, information should be given to the population when hourly means exceed 180 $\mu g/m^3$ and an alert warning should be issued if hourly means exceed 240 $\mu g/m^3$.

EU's long-term objective for the protection of human health defines 120 $\mu g/m^3$ as the maximum daily 8-hour mean value to occur within a calendar year. The long-term objective for the protection of vegetation is defined as an AOT40-value of 6000 $\mu g/m^3h$ for the period May-July. Community progress towards attaining the long-term objective using the year 2020 as a benchmark, shall be reviewed.

WHO has also defined air quality guidelines for the protection of human health and provided a global update of these levels, including a new guideline for ground-level ozone, in 2005 (WHO, 2006). Additionally, within both WHO, EU and UN-ECE the parameter SOMO35, defined as the sum of maximum 8-hour ozone levels over 35 ppb, is used as an indicator for health effects without any specified threshold level.

Flux-based critical levels for various types of vegetation have been approved for inclusion in the LRTAP Convention's modelling and mapping manual (CLRTAP, 2011). The DO^3SE-model is used to estimate the stomatal ozone flux as a function of the ozone concentration at the leaf boundary layer, the transfer of ozone across this boundary layer, the stomatal conductance to ozone and the ozone deposition to the leaf cuticle. The accumulated stomatal flux over a specified time interval is estimated by the parameter POD_Y (the Phytotoxic Ozone Dose over a threshold flux of Y nmol m^{-2} PLA s^{-1}|). In this context, Y represents a detoxification threshold, below which it is assumed that any ozone absorbed by the plant will be detoxified. Thus, POD_Y can be described as the "effective dose" or "effective flux". POD_Y is the flux-based analogy to the concentration-based AOT.

3. Measurement network

Surface ozone measurements have been a part of the EMEP extended (voluntary) measurement activities since the third phase (1 January 1984–31 December 1986). Due to the lack of funds, the systematic collection and checking of data within EMEP, did not start until 1 January 1987. The measurement of ozone data within the EMEP region was a continuation of the OECD's oxidant data collection programme OXIDATE. Ozone data from the OXIDATE-project have been reported in three reports (Grennfelt and Schjoldager, 1984; Grennfelt et al., 1988 and 1989).

This report presents surface ozone data measured at rural background EMEP-sites during 2019, with emphasis on statistical summaries and geographical distributions. Earlier reports are listed in Annex 5.

Table 3 and Figure 1 show the location of the monitoring stations reporting data from whole or part of 2019. In total, 139 stations from 28 different countries reported data. One of these sites (Ispra) is operated by the Commission of the European communities in Italy.

Table 3: List of EMEP ozone monitoring stations in operation 2019.

Code	Station name	Latitude	Longitude	Altitude
AT0002R	Illmitz	47°46'00"N	16°46'00"E	117
AT0005R	Vorhegg	46°40'40"N	12°58'20"E	1020
AT0030R	Pillersdorf bei Retz	48°43'16"N	15°56'32"E	315
AT0032R	Sulzberg	47°31'45"N	09°55'36"E	1020
AT0034G	Sonnblick	47°03'16"N	12°57'30"E	3106
AT0038R	Gerlitzen	46°41'37"N	13°54'54"E	1895
AT0040R	Masenberg	47°20'53"N	15°52'56"E	1170
AT0041R	Haunsberg	47°58'23"N	13°00'58"E	730
AT0042R	Heidenreichstein	48°52'43"N	15°02'48"E	570
AT0043R	Forsthof	48°06'22"N	15°55'10"E	581
AT0045R	Dunkelsteinerwald	48°22'16"N	15°32'48"E	320
AT0046R	Gänserndorf	48°20'05"N	16°43'50"E	161
AT0047R	Stixneusiedl	48°03'03"N	16°40'36"E	240
AT0048R	Zoebelboden	47°50'19"N	14°26'29"E	899
AT0049R	Grebenzen bei St. Lamprecht	47°02'25"N	14°19'48"E	1648
AT0050R	Graz Lustbuehel	47°04'01"N	15°29'37"E	481
BE0001R	Offagne	49°52'40"N	05°12'13"E	430
BE0032R	Eupen	50°37'46"N	06°00'04"E	295
BE0035R	Vezin	50°30'12"N	04°59'22"E	160
BG0053R	Rojen peak	41°41'45"N	24°44'19"E	1750
CH0001G	Jungfraujoch	46°32'51"N	07°59'06"E	3578
CH0002R	Payerne	46°48'47"N	06°56'41"E	489
CH0003R	Tänikon	47°28'47"N	08°54'17"E	539
CH0004R	Chaumont	47°02'59"N	06°58'46"E	1137
CH0005R	Rigi	47°04'03"N	08°27'50"E	1031
CH0053R	Beromünster	47°11'23"N	08°10'32"E	797
CY0002R	Agia Marina	35°02'21"N	33°03'29"E	532
CZ0001R	Svratouch	49°44'06"N	16°02'03"E	735
CZ0003R	Košetice (NOAK)	49°35'00"N	15°05'00"E	534
CZ0005R	Churanov	49°04'00"N	13°36'00"E	1118
DE0001R	Westerland	54°55'32"N	08°18'35"E	12
DE0002R	Waldhof	52°48'08"N	10°45'34"E	74
DE0003R	Schauinsland	47°54'53"N	07°54'31"E	1205
DE0007R	Neuglobsow	53°10'00"N	13°02'00"E	62
DE0008R	Schmücke	50°39'00"N	10°46'00"E	937
DE0009R	Zingst	54°26'00"N	12°44'00"E	1
DE0054R	Zugspitze-Schneefernhaus	47°24'59"N	10°58'47"E	2671
DK0005R	Keldsnor	54°44'47"N	10°44'10"E	10
DK0010G	Villum Research Station, Station Nord	81°36'00"N	16°40'12"W	20
DK0012R	Risoe	55°41'37"N	12°05'09"E	3
DK0025G	Summit	72°34'48"N	38°28'48"W	3238
DK0031R	Ulborg	56°17'26"N	08°25'39"E	10
EE0009R	Lahemaa	59°30'00"N	25°54'00"E	32
EE0011R	Vilsandi	58°23'00"N	21°49'00"E	6
ES0001R	San Pablo de los Montes	39°32'52"N	04°20'55"W	917
ES0005R	Noia	42°43'41"N	05°55'25"W	683

Table 3, cont.

Code	Station name	Latitude	Longitude	Altitude
ES0006R	Mahón	39°52'00"N	04°19'00"E	78
ES0007R	Víznar	37°14'00"N	03°32'00"W	1265
ES0008R	Niembro	43°26'32"N	04°51'01"W	134
ES0009R	Campisábalos	41°16'52"N	03°08'34"W	1360
ES0010R	Cabo de Creus	42°19'10"N	03°19'01"E	23
ES0011R	Barcarrota	38°28'33"N	06°55'22"W	393
ES0012R	Zarra	39°05'10"N	01°06'07"W	885
ES0013R	Penausende	41°17'00"N	05°52'00"W	985
ES0014R	Els Torms	41°24'00"N	00°43'00"E	470
ES0016R	O Saviñao	43°13'52"N	07°41'59"W	506
ES0017R	Doñana	37°01'50"N	06°19'55"W	5
FI0009R	Utö	59°46'45"N	21°22'38"E	7
FI0018R	Virolahti III	60°31'48"N	27°40'03"E	4
FI0022R	Oulanka	66°19'13"N	29°24'06"E	310
FI0096G	Pallas (Sammaltunturi)	68°00'00"N	24°09'00"E	340
FR0008R	Donon	48°30'00"N	07°08'00"E	775
FR0009R	Revin	49°54'00"N	04°38'00"E	390
FR0010R	Morvan	47°16'00"N	04°05'00"E	620
FR0013R	Peyrusse Vieille	43°37'00"N	00°11'00"E	200
FR0014R	Montandon	47°18'00"N	06°50'00"E	836
FR0015R	La Tardière	46°39'00"N	00°45'00"W	133
FR0016R	Le Casset	45°00'00"N	06°28'00"E	1750
FR0017R	Montfranc	45°48'00"N	02°04'00"E	810
FR0018R	La Coulonche	48°38'00"N	00°27'00"W	309
FR0023R	Saint-Nazaire-le-Désert	44°34'10"N	05°16'44"E	605
FR0025R	Verneuil	46°48'53"N	02°36'36"E	182
FR0030R	Puy de Dôme	45°46'00"N	02°57'00"E	1465
GB0002R	Eskdalemuir	55°18'47"N	03°12'15"W	243
GB0006R	Lough Navar	54°26'35"N	07°52'12"W	126
GB0013R	Yarner Wood	50°35'47"N	03°42'47"W	119
GB0014R	High Muffles	54°20'04"N	00°48'27"W	267
GB0015R	Strath Vaich Dam	57°44'04"N	04°46'28"W	270
GB0031R	Aston Hill	52°30'14"N	03°01'59"W	370
GB0033R	Bush	55°51'31"N	03°12'18"W	180
GB0037R	Ladybower Res.	53°23'56"N	01°45'12"W	420
GB0038R	Lullington Heath	50°47'34"N	00°10'46"E	120
GB0039R	Sibton	52°17'38"N	01°27'47"E	46
GB0043R	Narberth	51°14'00"N	04°42'00"W	160
GB0045R	Wicken Fen	52°17'54"N	00°17'34"W	5
GB0048R	Auchencorth Moss	55°47'32"N	03°14'34"W	260
GB0049R	Weybourne	52°57'02"N	01°07'19"E	16
GB0050R	St. Osyth	51°46'41"N	01°04'56"E	8
GB0052R	Lerwick	60°08'21"N	01°11'07"W	85
GB0053R	Charlton Mackrell	51°03'23"N	02°41'00"W	54
GB1055R	Chilbolton Observatory	51°08'59"N	01°26'18"W	78
GR0001R	Aliartos	38°22'00"N	23°05'00"E	110
GR0002R	Finokalia	35°19'00"N	25°40'00"E	250
HU0002R	K-puszta	46°58'00"N	19°35'00"E	125
IE0001R	Valentia Observatory	51°56'23"N	10°14'40"W	11
IE0031R	Mace Head	53°10'00"N	09°30'00"W	15
IT0004R	Ispra	45°48'00"N	08°38'00"E	209
IT0009R	Mt Cimone	44°11'00"N	10°42'00"E	2165
IT0018R	Lampedusa	35°31'06"N	12°37'50"E	45
IT0019R	Monte Martano	42°48'20"N	12°33'56"E	1090
LT0015R	Preila	55°21'00"N	21°04'00"E	5
LV0010R	Rucava	56°09'43"N	21°10'23"E	18
LV0016R	Zoseni	57°08'07"N	25°54'20"E	188
MK0007R	Lazaropole	41°32'10"N	20°41'38"E	1332
MT0001R	Giordan lighthouse	36°04'24"N	14°13'09"E	167
NL0007R	Eibergen	52°05'00"N	06°34'00"E	20
NL0009R	Kollumerwaard	53°20'02"N	06°16'38"E	1
NL0010R	Vredepeel	51°32'28"N	05°51'13"E	28
NL0091R	De Zilk	52°18'00"N	04°30'00"E	4
NL0644R	Cabauw Wielsekade	51°58'28"N	04°55'25"E	1

Table 3, cont.

Code	Station name	Latitude	Longitude	Altitude
NO0002R	Birkenes II	58°23'19"N	08°15'07"E	219
NO0015R	Tustervatn	65°50'00"N	13°55'00"E	439
NO0039R	Kårvatn	62°47'00"N	08°53'00"E	210
NO0042G	Zeppelin mountain (Ny-Ålesund)	78°54'24"N	11°53'18"E	474
NO0043R	Prestebakke	59°00'00"N	11°32'00"E	160
NO0052R	Sandve	59°12'00"N	05°12'00"E	15
NO0056R	Hurdal	60°22'21"N	11°04'41"E	300
PL0002R	Jarczew	51°49'00"N	21°59'00"E	180
PL0003R	Sniezka	50°44'00"N	15°44'00"E	1603
PL0004R	Leba	54°45'00"N	17°32'00"E	2
PL0005R	Diabla Gora	54°09'00"N	22°04'00"E	157
RS0005R	Kamenici Vis	43°24'00"N	21°57'00"E	813
SE0005R	Bredkälen	63°51'00"N	15°20'00"E	404
SE0013R	Esrange	67°53'00"N	21°04'00"E	475
SE0014R	Råö	57°23'38"N	11°54'50"E	5
SE0018R	Asa	57°09'52"N	14°46'57"E	180
SE0019R	Östad	57°57'09"N	12°24'11"E	65
SE0020R	Hallahus	56°02'34"N	13°08'53"N	190
SE0022R	Norunda Stenen	60°05'09"N	17°30'19"E	45
SE0032R	Norra-Kvill	57°49'00"N	15°34'00"E	261
SE0035R	Vindeln	64°15'00"N	19°46'00"E	225
SE0039R	Grimsö	59°43'41"N	15°28'19"E	132
SI0008R	Iskrba	45°34'00"N	14°52'00"E	520
SI0031R	Zarodnje	46°25'43"N	15°00'12"E	770
SI0032R	Krvavec	46°17'58"N	14°32'19"E	1740
SK0002R	Chopok	48°56'00"N	19°35'00"E	2008
SK0004R	Stará Lesná	49°09'00"N	20°17'00"E	808
SK0006R	Starina	49°03'00"N	22°16'00"E	345
SK0007R	Topolniky	47°57'36"N	17°51'38"E	113

The monitoring stations are selected by the countries. Information about the ozone data quality, calibration and maintenance procedures was in 2000 collected from the participants (Aas et al., 2000).

The UV absorption method is the only measurement method in use in 2019. The monitors measure the mixing ratio (in nmol/mol), whereas all data presented in this report are given in µg/m^3. The CCC accepts data submissions in both nmol/mol and ug/m3, however, if submitting in ug/m3 the temperature and pressure used to convert from nmol/mol to ug/m3 should be provided in the meta data. The only site not using the standard conditions of 20 C and 1013 hPa is the high-altitude site Jungfraujoch, where annual mean conditions (-8˚C, 653 hPa) are used. For sites reporting in mixing ratio, data are converted to ug/m3 using standard conditions, corresponding to a conversion factor of 2.0.

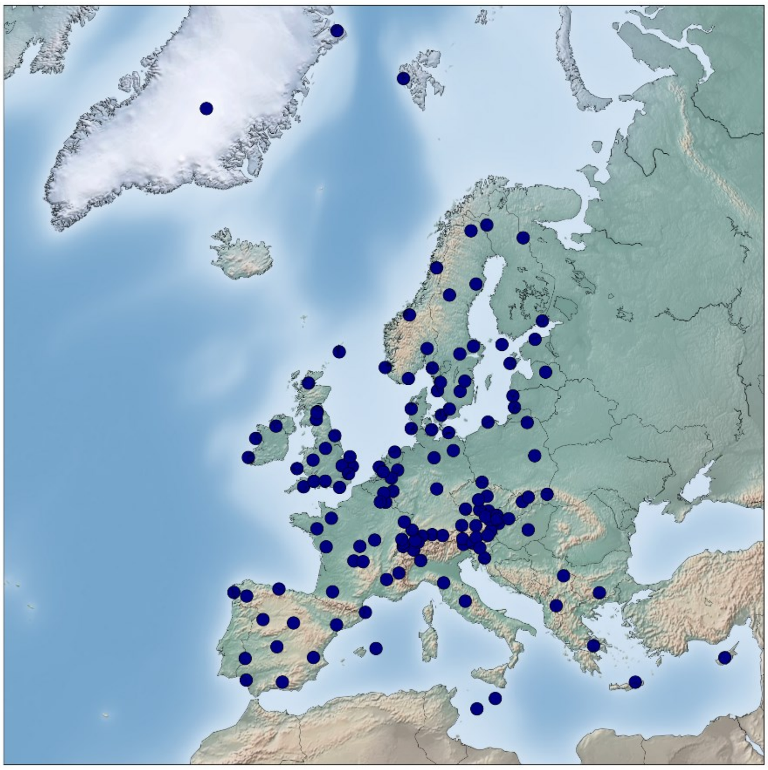


Figure 1: Location of the monitoring stations.

4. Data completeness

The annual means and data capture (number of valid measurements in percent of the total number of measurements) for each station is given in Table 1, Annex 1. The data capture is in general good, 120 stations have a data capture above 90%.

Missing data in the measurement series may be critical when calculating aggregated ozone metrics, especially in summer when the highest ozone concentrations occur. In particular, calculations of AOT40 values may be strongly affected by missing data, and a correction is necessary in order to obtain comparable calculations. In the mapping of AOT40, a data capture of 85% is required and an adjustment proportional to the number of missing data is applied, i.e. exposure index divided by the fraction of data available. This correction gives a good approximation when the missing data are randomly scattered throughout the dataset, but a better correction is needed for larger gaps in the dataset. Calculations of percentiles are less sensitive to missing data, and a data capture of 75% is regarded as sufficient for the mapping.

5. Concentration summaries and episodes

The global mean temperature in 2019 was reported by the World Meteorological Organisation (WMO, 2020) as the second or third highest on record. In Europe, the annual mean temperature for 2019 was the highest on record according to Copernicus.During the summer season, Europe was affected by four main ozone episodes that occurred[1] around days 23-28 in each of the months April, June, July, and August at a varying degree in different parts of the continent. The ozone episodes in June and July were linked to extreme heat waves in which new national temperature records were set

[1] https://climate.copernicus.eu/ESOTC/2019/european-temperature

in France, Germany, United Kingdom, Belgium and the Netherlands (Overland et al., 2019). During these episodes EU's information threshold (180 µg/m^3) was broken in many countries and even the alert threshold (240 µg/m^3) was broken at a few sites. Some stations recorded the highest ozone concentrations since the 1990s.

Overall, the number of ozone exceedances in 2019 was comparable to the level in 2018 and 2015. During the past decades, the summers of 2003 and 2006 had very large number of exceedances, principally due to very warm weather during summer (EEA, 2011).

The highest one-hour ozone concentrations in 2019 were measured at Ispra in Italy (284 µg/m^3, June 28), at Cabauw in the Netherlands (257 µg/m^3, July 25) and Vredepeel, The Netherlands (254 µg/m^3, July 28) (Figure 2, Table A.1, Annex 1). In total, concentrations above 200 µg/m^3 were measured at 14 sites in Europe. The lowest maximum concentrations were measured at the remote sites Villum research station, Station Nord in Greenland (98 µg/m^3) and Zeppelin mountain, Spitsbergen (114 µg/m^3).

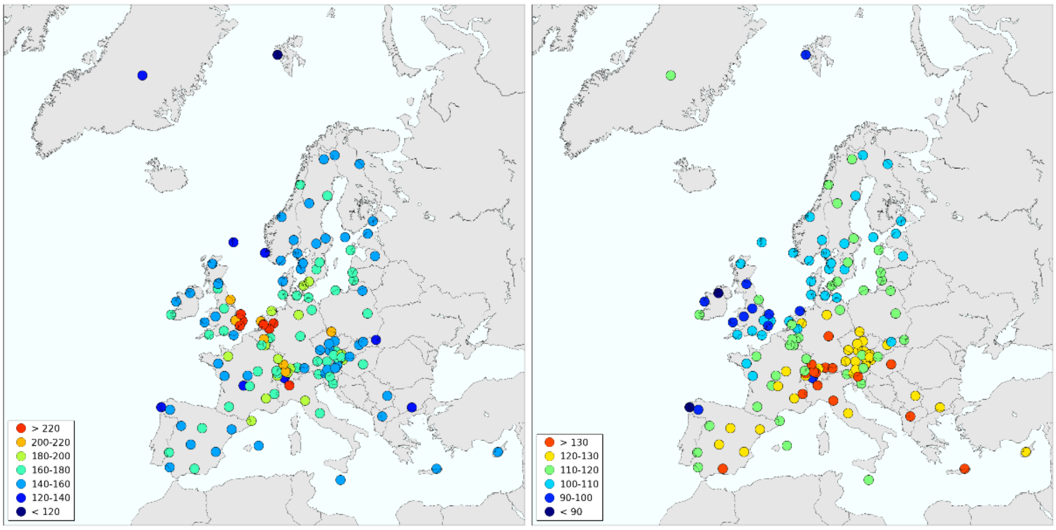


Figure 2: Maximum concentration (left), Hourly 95-percentile April-September (right) 2019. Unit µg/m^3

Exceedances of the information threshold of 180 µg/m^3 were observed at 29 sites generally in Central Europe; Belgium, The Netherlands, France, The UK, Austria and Switzerland. This compares to 26 sites in 2018 and 33 sites in 2015. In the unusual warm summers of 2003 and 2006, the information threshold was exceeded at 81 and 69 sites respectively.

Graphical distributions of the 95-percentile for stations with data capture higher than 75% are shown in Figure 2. The lowest values are found in Scandinavia, Ireland and the UK, where the 95-percentiles are below 110 µg/m^3. The concentrations are higher in Poland and the Baltics, where the 95-percentiles generally ranges from 110-130 µg/m^3, and at its highest in Italy, Slovenia, Austria, and Switzerland, where the 95-percentile values are above 130 µg/m^3.

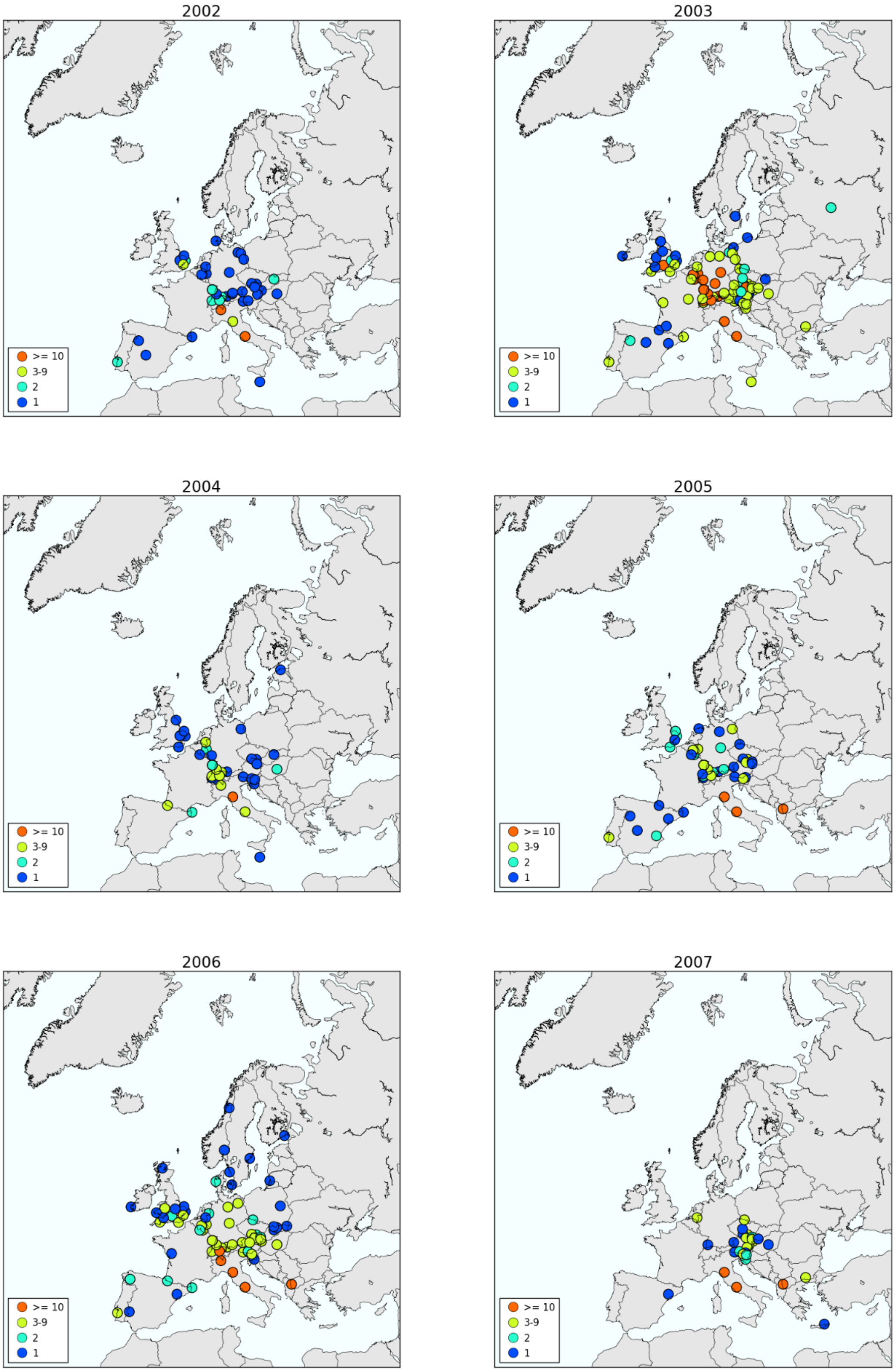


Figure 3: Number of exceedances of the threshold value of 180 μg/m³ 2002-2019. (Unit: number of days.) Stations with zero exceedances are not shown.

Figure 3, cont.:

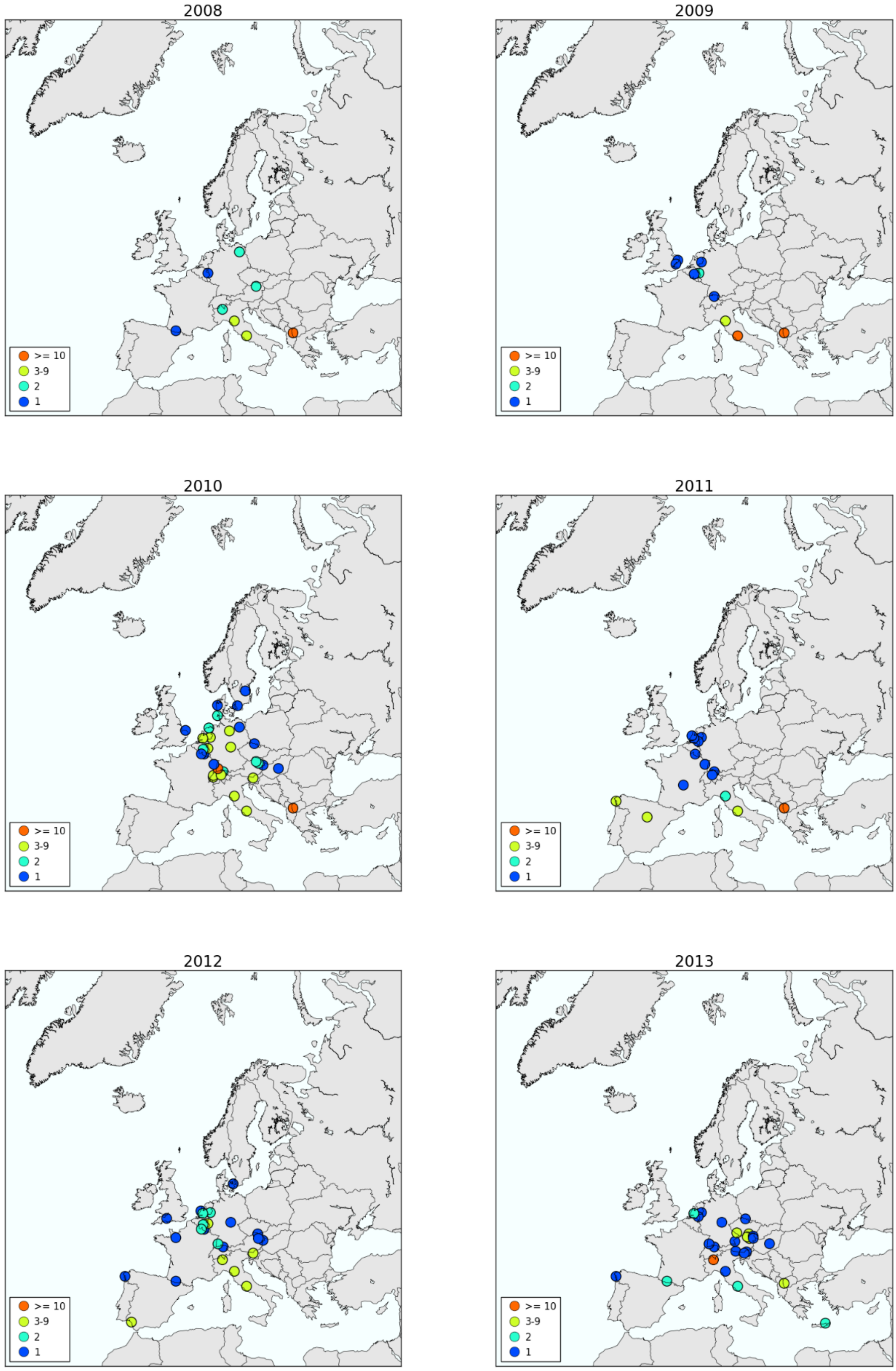
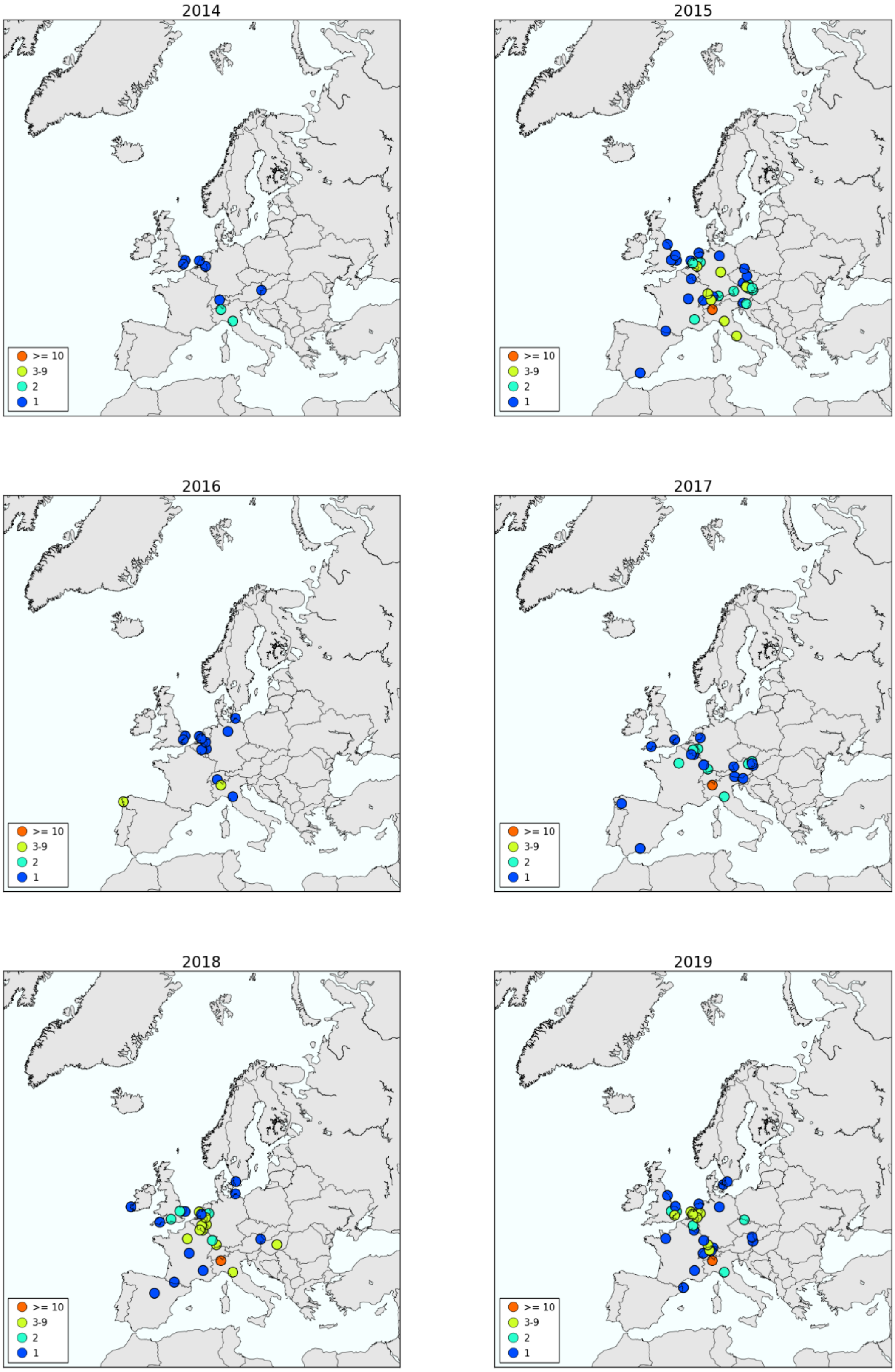


Figure 3, cont.:



6. Calculation of AOT40

AOT40 for forest and agricultural crops for 2019 are shown in Table A.1, Annex 1, and the corresponding geographical distributions of AOT40 are shown in Figure 4. The maps of AOT40 show a general increasing gradient from west to east and from north to south. Low values are found in most parts of Northern Europe, while the highest values are found in Central Europe. Ten sites in Europe had 3-months AOT40 (May-July) values above 15 000 ppbh. The critical level for forest (5 000 ppbh) for 6-months AOT40 (April-September) was exceeded at most sites in Central, Eastern and Southern Europe.

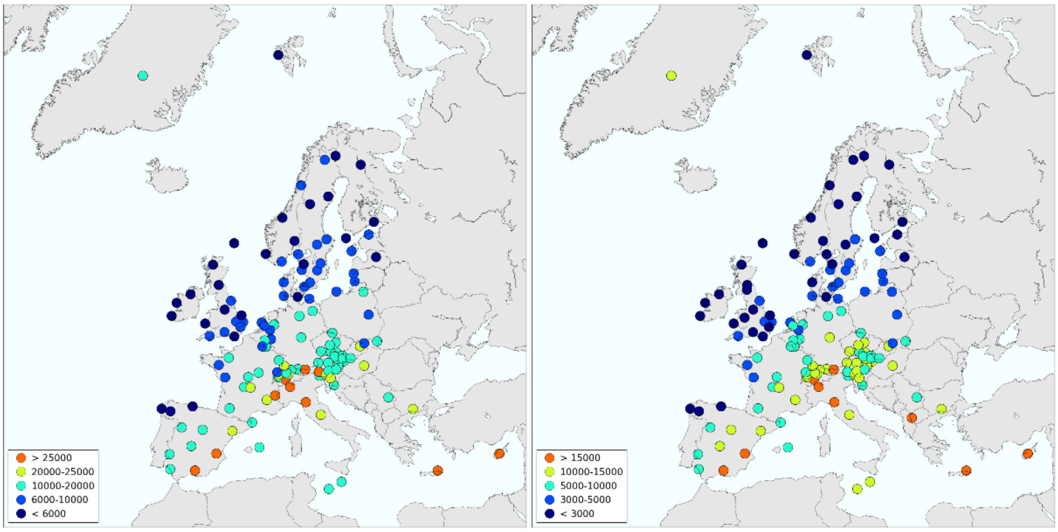


Figure 4: AOT40 2019 08-20 CET; April-September (left) and May-July (right). Unit: ppb hours

7. Update

The data compiled in this report represent the quality assured and quality-controlled data at present. If errors are detected in the future, the data will be corrected in the database. It is important that users make certain they have access to the most recent version of the data. For the data presented here, the latest alteration was August 23, 2021.

All EMEP measurement data can be downloaded online at http://ebas.nilu.no or sent upon request to ebas@nilu.no. Information on EMEP and the measurement network are available at http://www.emep.int and http://www.nilu.no/projects/ccc.

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9. Acknowledgements

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Closer at home, secretarial work, data flow and data base maintenance has been performed by Berit Modalen, Ann Mari Fjæraa, Rita Larsen Våler and Mona Waagsbø.

10. List of participating institutions

Armenia	Environmental Monitoring and Information Center
Austria	Umweltbundesamt Provincial Government of Tyrol Provincial Government of Carinthia Environment Institute Vorarlberg Provincial Government Styria Provincial Government Salzburg Provincial Government Lower Austria
Belgium	Belgian Interregional Environment Agency (IRCEL – CELINE)
Bulgaria	Executive Environment Agency of Bulgaria
Commission of the European Communities	Joint Research Center. EC-JRC
Cyprus	Ministry of Labour, Welfare and Social Insurance
Czech Republic	Czech Hydrometeorological Institute
Denmark	Department of Environmental Science, Aarhus University
Estonia	Estonian Environmental Research Centre
Finland	Finnish Meteorological Institute (FMI)
France	IMT Lille Douai
Germany	Umweltbundesamt
Greece	University of Crete Hellenic Ministry of the Environment and Energy
Hungary	Hungarian Meteorological Service
Ireland	Environmental Protection Agency (EPA) Ricardo – AEA
Italy	CNR-ISAC
Latvia	Latvian Environment, Geology and Meteorology Agency
Lithuania	SRI Center for Physical Sciences and Technology
Macedonia	Ministry of Environment and Physical Planning
Malta	Department of Geoscience, University of Malta
Netherlands	National Institute for Public Health and the Environment (RIVM)
Norway	Norwegian Institute for Air Research (NILU)
Poland	Institute of Meteorology and Water Management Institute of Environmental Protection
Slovakia	Slovak Hydrometeorological Institute
Slovenia	Slovenian Environment Agency
Spain	Ministerio para la Transicion Ecologica, Agencia Estatal de Meteorologia
Sweden	Swedish Environmental Research Institute (IVL)
Switzerland	Swiss Federal Laboratory of Materials Science and Technology (EMPA)
United Kingdom	Ricardo – AEA

Annex 1

Statistical summary 2019

Table A.1: Statistical summary of ozone data 2019.

Station code	Station name	Annual average µg/m³	Annual data capture %	95-percentile µg/m³	Maximum concentration value µg/m³	Maximum concentration date	# days >180 days	AOT40 Apr-Sep ppbh	AOT40 May-Jul ppbh	SOMO35 ppbd
AT0002R	Illmitz	64.9	94.6	127.9	182.6	2019-06-27	1	19946	11755	3790
AT0005R	Vorhegg	69.8	89.4	116.3	163.0	2019-06-30	0	10082	7110	2994
AT0030R	Pillersdorf bei Retz	66.1	94.8	124.9	160.2	2019-07-01	0	17911	10729	3442
AT0032R	Sulzberg	80.4	94.9	130.9	170.6	2019-07-26	0	16554	11597	4379
AT0034G	Sonnblick	97.9	95.4	124.4	166.4	2019-03-20	0	58313	32836	12302
AT0038R	Gerlitzen	91.0	95.7	129.1	157.7	2019-07-06	0	20926	13093	5423
AT0040R	Masenberg	81.3	93.9	126.3	154.0	2019-07-01	0	18212	11250	4275
AT0041R	Haunsberg	72.6	95.3	129.2	174.8	2019-06-26	0	15727	11387	3723
AT0042R	Heidenreichstein	61.7	95.4	120.0	153.0	2019-06-27	0	14657	8974	3070
AT0043R	Forsthof	70.7	95.0	127.7	167.1	2019-06-14	0	17397	10882	3608
AT0045R	Dunkelsteinerwald	55.8	95.5	118.5	163.7	2019-07-01	0	12757	8079	2741
AT0046R	Gänserndorf	59.2	95.4	121.2	196.5	2019-07-01	1	15649	9035	3038
AT0047R	Stixneusiedl	63.2	94.7	121.3	164.4	2019-07-01	0	15458	9024	3208
AT0048R	Zoebelboden	77.3	93.3	127.8	171.0	2019-07-26	0	14411	10417	3816
AT0049R	Grebenzen bei St. Lamprecht	90.2	93.8	127.1	152.8	2019-07-25	0	19160	12571	5295
AT0050R	Graz Lustbuehel	59.9	95.0	115.6	148.8	2019-06-27	0	11941	7231	2952
BE0001R	Offagne	60.1	95.9	113.5	182.5	2019-07-25	1	10367	6828	2092
BE0032R	Eupen	54.9	95.1	116.0	178.0	2019-06-26	0	9801	5822	1800
BE0035R	Vezin	50.7	95.4	118.0	208.0	2019-07-26	2	11432	7015	2078
BG0053R	Rojen peak	92.2	93.1	123.7	138.1	2019-08-29	0	23464	10596	5671
CH0001G	Jungfraujoch	74.3	96.9	99.5	130.5	2019-06-16	0	37457	21750	8169
CH0002R	Payerne	56.7	98.4	121.8	180.9	2019-07-24	1	16818	11604	3047
CH0003R	Tänikon	56.4	99.2	124.6	196.2	2019-06-27	1	15878	11567	2952
CH0004R	Chaumont	83.8	95.4	134.9	175.4	2019-07-25	0	21152	13406	4599
CH0005R	Rigi	82.5	99.2	134.8	195.9	2019-06-27	1	21378	14374	4699
CH0053R	Beromünster	73.2	98.6	131.4	203.7	2019-06-26	3	18994	12783	3762
CY0002R	Ayia Marina	95.6	96.2	128.9	155.7	2019-06-26	0	28216	15204	6299
CZ0001R	Svratouch	74.5	89.0	122.5	145.8	2019-06-20	0	18522	10926	3216
CZ0003R	Kosetice	65.7	93.7	120.5	143.6	2019-06-27	0	16531	10180	2846
CZ0005R	Churanov	77.8	96.3	125.1	156.4	2019-07-26	0	18164	10756	3763
DE0001R	Westerland	68.5	99.4	109.5	170.1	2019-06-25	0	9687	4922	2860
DE0002R	Waldhof	57.2	93.9	126.1	196.4	2019-06-30	1	15917	8981	2634
DE0003R	Schauinsland	84.2	92.9	146.7	217.6	2019-07-25	4	21961	12549	4631

Station code	Station name	Annual average µg/m³	Annual data capture %	95-percentile µg/m³	Maximum concentration value µg/m³	Maximum concentration date	# days >180 days	AOT40 Apr-Sep ppbh	AOT40 May-Jul ppbh	SOMO35 ppbd
DE0007R	Neuglobsow	55.6	98.5	118.6	179.0	2019-06-26	0	13387	6973	2470
DE0008R	Schmücke	75.4	95.3	132.9	163.9	2019-06-30	0	18130	10294	3719
DE0009R	Zingst	61.2	95.1	109.6	172.0	2019-06-30	0	8884	4518	1967
DE0054R	Schneefernerhaus	97.4	98.7	131.4	157.1	2019-07-24	0	27561	17470	6549
DK0005R	Keldsnor	61.1	89.4	103.8	172.6	2019-06-30	0	5211	2362	1794
DK0010G	Villum Research Station, Station Nord	70.6	72.3	87.7	98.4	2019-12-30	0	771	74	1495
DK0012R	Risoe	62.7	89.9	110.5	182.9	2019-06-30	1	8846	4172	2181
DK0025G	Summit	88.7	99.1	117.4	133.4	2019-08-03	0	18269	10782	4411
DK0031R	Ulborg	62.4	89.0	106.3	148.7	2019-08-28	0	6119	2464	1686
EE0009R	Lahemaa	56.0	99.9	106.9	155.2	2019-07-26	0	6737	2935	1582
EE0011R	Vilsandi	69.1	98.4	113.4	166.9	2019-04-24	0	8964	3894	2599
ES0001R	San Pablo de los Montes	85.0	96.6	121.3	142.1	2019-07-24	0	19912	10710	4647
ES0005R	Noya	60.7	99.3	87.1	120.4	2019-03-31	0	758	159	1011
ES0006R	Mahón	83.5	97.1	117.4	142.0	2019-08-31	0	17699	8551	4433
ES0007R	Víznar	87.8	97.1	130.0	167.7	2019-06-29	0	28122	15718	5505
ES0008R	Niembro	78.4	68.6	105.6	126.5	2019-02-01	0	4829	2237	2415
ES0009R	Campisabalos	75.7	98.3	121.1	164.6	2019-07-25	0	19779	11851	3942
ES0010R	Cabo de Creus	76.9	97.7	115.0	186.1	2019-06-28	1	12456	5674	3227
ES0011R	Barcarrota	64.0	97.8	114.3	167.9	2019-07-21	0	14773	7497	3223
ES0012R	Zarra	89.3	98.6	129.8	158.1	2019-07-12	0	27621	16712	5581
ES0013R	Penausende	74.0	98.0	118.2	145.8	2019-07-11	0	14900	8526	3468
ES0014R	Els Torms	78.9	98.8	123.0	151.5	2019-07-04	0	21899	12565	4435
ES0016R	O Saviñao	58.2	98.1	93.2	143.3	2019-08-23	0	3210	1407	1394
ES0017R	Doñana	63.5	98.6	110.2	140.6	2019-04-22	0	11751	5582	3175
FI0009R	Utö	67.2	99.1	103.5	141.8	2019-04-25	0	5539	2451	1854
FI0018R	Virolahti III	54.6	99.8	101.6	146.4	2019-06-06	0	5810	2242	1363
FI0022R	Oulanka	58.1	99.6	103.1	149.2	2019-04-26	0	4029	508	1086
FI0096G	Pallas (Sammaltunturi)	67.1	99.6	108.4	145.7	2019-04-23	0	4809	830	1645
FR0008R	Donon	68.4	95.1	117.9	181.0	2019-07-25	1	11164	7206	2578
FR0009R	Revin	64.9	89.4	118.7	176.4	2019-07-25	0	9216	5162	2127
FR0010R	Morvan	73.3	92.9	127.9	168.0	2019-07-25	0	19537	11411	3527
FR0013R	Peyrusse Vieille	69.8	98.3	114.3	173.4	2019-07-22	0	10584	6070	2919
FR0014R	Montandon	59.7	97.8	111.9	172.0	2019-07-25	0	9241	6642	2123
FR0015R	La Tardière	60.9	98.2	108.2	142.1	2019-07-04	0	7366	4795	2099
FR0016R	Le Casset	96.4	92.5	136.9	173.0	2019-04-05	0	31760	18659	5972

Station code	Station name	Annual average µg/m³	Annual data capture %	95-percentile µg/m³	Maximum concentration value µg/m³	Maximum concentration date	# days >180 days	AOT40 Apr-Sep ppbh	AOT40 May-Jul ppbh	SOMO35 ppbd
FR0017R	Montfranc	78.1	97.0	116.9	137.9	2019-04-15	0	13520	6492	3371
FR0018R	La Coulonche	69.8	99.6	113.9	195.9	2019-06-28	1	10271	5858	2591
FR0023R	Saint-Nazaire-le-Désert	66.8	98.4	125.9	185.0	2019-06-25	1	21874	12706	4043
FR0024R	Guipry	57.1	94.5	104.0	156.0	2019-06-27	0	7501	4779	1900
FR0025R	Verneuil	60.0	98.5	112.9	159.0	2019-07-25	0	11943	6618	2499
FR0030R	Puy de Dôme	89.3	97.7	128.9	166.6	2019-07-05	0	20951	11344	5221
GB0002R	Eskdalemuir	60.0	85.2	100.8	162.3	2019-04-21	0	5970	1729	1205
GB0006R	Lough Navar	49.3	97.8	87.5	153.4	2019-04-22	0	2165	762	811
GB0013R	Yarner Wood	62.7	95.7	103.2	161.8	2019-04-20	0	6268	3056	1729
GB0014R	High Muffles	65.0	98.3	117.0	203.8	2019-07-25	1	8781	3641	2151
GB0015R	Strath Vaich Dam	67.5	95.6	100.6	148.5	2019-04-22	0	4225	1397	1671
GB0031R	Aston Hill	64.9	87.5	96.3	151.7	2019-04-22	0	3723	1128	1347
GB0033R	Bush	59.6	79.1	99.7	158.5	2019-04-22	0	4447	429	1007
GB0037R	Ladybower Res.	56.5	96.0	98.4	169.2	2019-07-25	0	4326	1544	1167
GB0038R	Lullington Heath	61.3	98.1	100.9	159.0	2019-04-21	0	5411	2718	1762
GB0039R	Sibton	58.0	99.7	103.1	238.5	2019-07-25	2	7602	3211	1859
GB0043R	Narberth	54.5	98.9	90.6	146.8	2019-04-21	0	2069	640	812
GB0045R	Wicken Fen	51.6	96.6	103.7	212.0	2019-07-25	2	7109	3008	1542
GB0048R	Auchencorth Moss	59.5	99.7	93.2	147.1	2019-04-21	0	3327	947	1006
GB0049R	Weybourne	56.9	95.0	99.3	221.7	2019-07-25	1	4560	2314	1425
GB0050R	St. Osyth	55.8	99.3	99.0	233.2	2019-07-25	5	6068	2900	1607
GB0052R	Lerwick	72.1	99.2	104.9	139.6	2019-04-22	0	5612	1779	2209
GB0053R	Charlton Mackrell	54.1	37.4	97.5	163.2	2019-06-29	0	5526	3129	426
GB1055R	Chilbolton Observatory	55.5	96.9	101.4	171.2	2019-04-21	0	6215	2899	1651
GR0001R	Aliartos	63.3	48.0	127.0	144.0	2019-07-08	0	30728	17979	2552
GR0002R	Finokalia	98.1	90.3	134.1	158.5	2019-07-19	0	35841	18706	6249
HU0002R	K-puszta	63.1	90.5	131.7	167.7	2019-07-02	0	23290	12097	4335
IE0001R	Valentia Observatory	72.4	96.9	114.7	160.7	2019-05-24	0	5102	2643	3024
IE0031R	Mace Head	73.6	99.2	99.7	144.0	2019-04-22	0	3965	1681	2412
IT0004R	Ispra	51.4	99.5	146.3	284.6	2019-06-28	14	27270	18788	4462
IT0009R	Mt Cimone	100.1	96.8	137.3	197.7	2019-06-28	2	32529	18839	7016
IT0018R	Lampedusa	98.0	52.9	123.7	146.7	2019-06-28	0	16369	11105	3600
IT0019R	Monte Martano	84.8	95.5	126.9	165.5	2019-08-07	0	21307	12988	4318
LT0015R	Preila	66.1	99.1	110.2	164.9	2019-06-26	0	7845	3684	2639
LV0010R	Rucava	65.2	87.3	111.0	162.9	2019-06-26	0	9195	3759	2778

Station code	Station name	Annual average µg/m³	Annual data capture %	95-percentile µg/m³	Maximum concentration value µg/m³	date	# days >180 days	AOT40 Apr-Sep ppbh	AOT40 May-Jul ppbh	SOMO35 ppbd
LV0016R	Zoseni	54.4	76.6	101.5	158.5	2019-04-24	0	4314	1165	1172
MK0007R	Lazaropole	97.1	77.9	131.7	153.6	2019-07-08	0	34534	16500	5897
MT0001R	Giordan lighthouse	85.5	88.5	116.9	144.1	2019-07-19	0	19484	10546	3947
NL0007R	Eibergen	47.0	98.5	120.8	230.5	2019-07-25	3	10850	6604	1883
NL0009R	Kollumerwaard	49.5	90.0	93.0	188.2	2019-07-25	1	4116	2193	863
NL0010R	Vredepeel	44.7	98.6	108.5	254.9	2019-07-25	3	8048	4613	1475
NL0091R	De Zilk	53.1	98.5	106.2	203.1	2019-07-25	5	7653	4228	1842
NL0644R	Cabauw Wielsekade	48.0	98.5	112.0	257.9	2019-07-25	6	9338	5535	1856
NO0002R	Birkenes II	63.9	99.5	107.1	156.0	2019-04-21	0	7700	3400	2082
NO0015R	Tustervatn	69.7	99.3	116.8	164.5	2019-04-25	0	6644	1309	2137
NO0039R	Kårvatn	55.6	99.2	109.7	142.7	2019-04-24	0	5823	1200	1793
NO0042G	Zeppelin mountain (Ny-Ålesund)	69.7	98.7	95.1	114.0	2019-04-18	0	1958	396	1507
NO0043R	Prestebakke	59.2	98.9	105.5	145.2	2019-06-30	0	6183	2051	1465
NO0052R	Sandve	65.3	99.2	102.2	138.4	2019-08-26	0	4968	1433	1702
NO0056R	Hurdal	55.8	99.3	100.2	145.1	2019-04-24	0	4148	928	1310
PL0002R	Jarczew	62.2	100.0	112.6	170.5	2019-06-26	0	8231	3794	2286
PL0003R	Sniezka	74.1	98.6	120.2	208.8	2019-07-25	2	11464	6650	3722
PL0004R	Leba	62.2	100.0	112.6	170.5	2019-06-26	0	8231	3794	2286
PL0005R	Diabla Gora	57.0	96.8	113.3	145.9	2019-04-23	0	10441	4068	2016
RS0005R	Kamenicki vis	75.5	93.7	123.0	152.0	2019-07-31	0	19489	9515	3803
SE0005R	Bredkälen	62.1	95.1	111.2	152.1	2019-04-25	0	5800	1154	1632
SE0013R	Esrange	69.5	99.9	115.5	155.3	2019-04-26	0	6942	1742	2024
SE0014R	Råö	64.6	97.2	107.5	147.7	2019-06-19	0	7542	3600	1928
SE0018R	Asa	55.4	98.9	107.3	176.2	2019-06-30	0	7774	3546	1622
SE0019R	Östad	52.1	98.9	101.7	145.1	2019-06-30	0	5493	1941	1327
SE0020R	Hallahus	61.2	99.8	115.3	181.3	2019-06-30	1	9526	4178	1959
SE0022R	Norunda Stenen	56.8	98.8	113.5	159.4	2019-04-24	0	8845	3883	1873
SE0032R	Norra-Kvill	64.5	99.6	110.6	172.2	2019-06-30	0	8183	3477	1841
SE0035R	Vindeln	57.3	99.8	103.5	160.8	2019-04-25	0	5321	1494	1433
SE0039R	Grimsö	55.8	99.7	106.8	149.5	2019-06-30	0	6251	2131	1529
SI0008R	Iskrba	55.2	94.0	118.7	170.2	2019-07-06	0	15860	9054	3458
SI0032R	Krvavec	94.5	91.6	134.9	168.8	2019-07-06	0	23914	13973	6150
SK0002R	Chopok	89.9	91.6	126.0	156.0	2019-06-27	0	22090	11804	5459
SK0004R	Stará Lesná	58.7	94.3	102.0	144.0	2019-06-27	0	6975	4271	1886

Station code	Station name	Annual average µg/m³	Annual data capture %	95-percentile µg/m³	Maximum concentration value µg/m³	date	# days >180 days	AOT40 Apr-Sep ppbh	AOT40 May-Jul ppbh	SOMO35 ppbd
SK0006R	Starina	62.1	89.6	110.0	138.0	2019-04-20	0	11535	5676	2513
SK0007R	Topolniky	54.7	95.1	119.0	157.0	2019-07-05	0	14212	8619	2782

Annex 2

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