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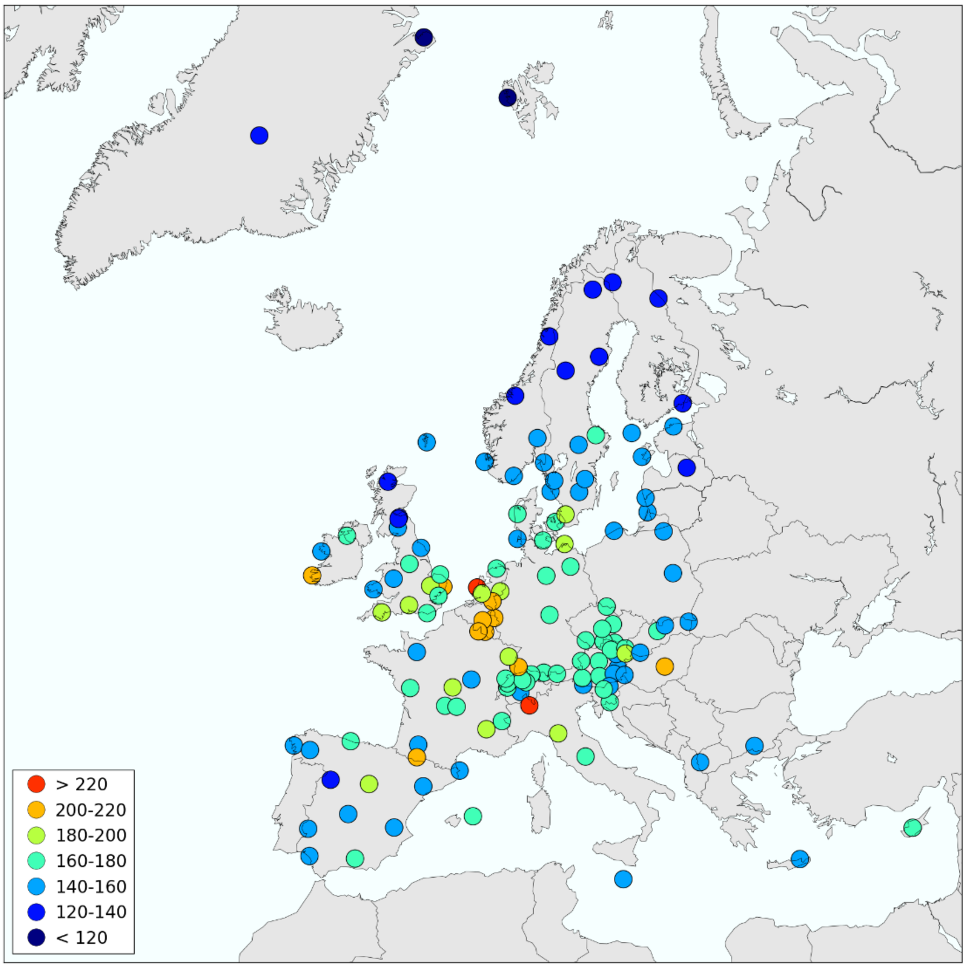
Co-operative Programme for Monitoring and Evaluation
of the Long-Range Transmission of Air Pollutants in Europe

Ozone measurements 2018

Anne-Gunn Hjellbrekke and Sverre Solberg



Maximum ozone concentration 2018 µg/m^3

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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 2018 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 (µg/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 $\mu g/m^3$ and a factor 2 $\mu g/m^3$ = 1 ppb

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

Value ($\mu g/m^3$)	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. To be fulfilled by 1.1.2010
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, to be met by 1.1.2010, is 120 µg/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 µg/m^{3}h averaged over five years. In addition, information should be given to the population when hourly means exceed 180 µg/m^3 and an alert warning should be issued if hourly means exceed 240 µg/m^3.

EU's long-term objective for the protection of human health defines 120 µg/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 µg/m^{3}h 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^{3}SE-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 2018, 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 2018. In total, 141 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 2018.

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
FR0019R	Pic du Midi	42°56'12"N	00°08'31"E	2877
FR0020R	SIRTA Atmospheric Research Observatory	48°42'31"N	02°09'32"E	162
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
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
HU0003R	Farkasfa	46°54'36"N	16°19'12"E	312
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). A document, ”Overview of the routines for calibration and maintenance”, is also available under the ozone section at http://www.nilu.no/projects/ccc/emepdata.html.

The UV absorption method is the only measurement method in use in 2018. The monitors measure the mixing ratio (in nmol/mol), whereas all data presented in this report are given in µg/m^3. The conversion factor used to calculate from nmol/mol to µg/m^3 is given in Table 4. Most countries use a conversion factor of 2.0, which corresponds to 20˚C and 1013 hPa. For the high altitude site Jungfraujoch in Switzerland, the mean annual conditions (-8˚C, 653 hPa) are used, giving a conversion factor of 1.42. A number of countries report ozone data in mixing ratio, and in this case the data are converted to µg/m^3 by multiplying by 2.0 at the CCC.

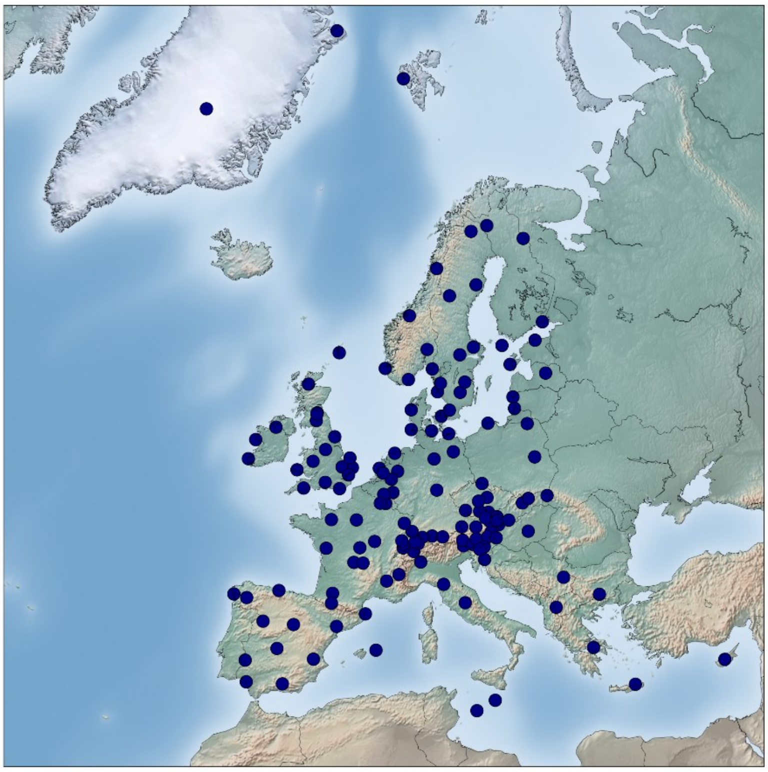


Figure 1: Location of the monitoring stations.

Table 4: Conversion factor ppb – $\mu g/m^3$.

Country	Conversion factor
Austria	2.0
Belgium	2.0
Bulgaria	
Cyprus	2.0
Czech Republic	Reported in mixing ratio
Denmark	2.0
Estonia	2.0
Finland	2.0
France	Reported in mixing ratio
Germany	Reported in mixing ratio
Greece (Aliartos)	1.96
Greece (Finokalia)	Reported in mixing ratio
Hungary	Reported in mixing ratio
Ireland (Mace Head)	Reported in mixing ratio
Italy	Reported in mixing ratio
Latvia	2.0
Lithuania	2.0
Malta	Reported in mixing ratio
Netherlands	2.0
Norway	2.0
Poland (IMWM)	2.0
Poland (Diabla Gora)	Reported in mixing ratio
Slovakia	2.0
Slovenia	Reported in mixing ratio
Spain	2.0
Sweden	2.0
Switzerland	2.0 (1.42 at CH0001R)
United Kingdom	Reported in mixing ratio

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, 117 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 40, 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 summer of 2018 was remarkable in the northern Europe, with a very persistent high-pressure system over Scandinavia causing high temperatures and drought, while southern Europe was unusually wet. Exceedances of the information threshold of 180 µg/m^3 occurred in both Sweden and Ireland for the first time in many years (Figure 3). Overall, the number of ozone exceedances in 2018 was comparable to the level in 2015, and higher than 2017 and 2016. 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 2018 were measured at Ispra in Italy (238 µg/m^3, July 26), at De Zilk in the Netherlands (226 µg/m^3, August 8) and SIRTA, France (226 µg/m^3, August 3) (Figure 2, Table A.1, Annex 1). In total, concentrations above 200 µg/m^3 were measured at 13 sites in Europe. The lowest maximum concentrations were measured at the remote sites Villum research station, Station Nord in Greenland (104 µg/m^3) and Zeppelin mountain, Spitsbergen (104 µg/m^3).

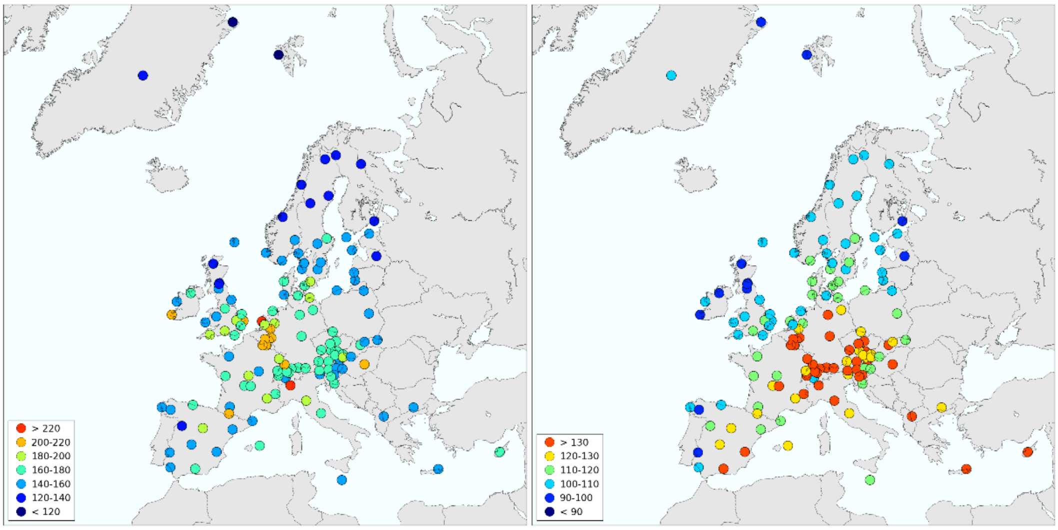


Figure 2: Maximum concentration (left), 95-percentile April-September (right) 2018. Unit µg/m³

Exceedances of the information threshold of 180 µg/m³ were observed at 26 sites, mostly in Central Europe: Belgium, the Netherlands, Germany, France and Italy. This compares to 21 sites in 2017, 14 sites in 2016 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 Scotland, where the 95-percentiles are below 110 µg/m³. The concentrations are higher in England, Poland and the Baltics, where the 95-percentiles generally ranges from 110-130 µg/m³, and at its highest in Italy, Slovenia, Austria and Switzerland, where the 95-percentile values are above 130 µg/m³.

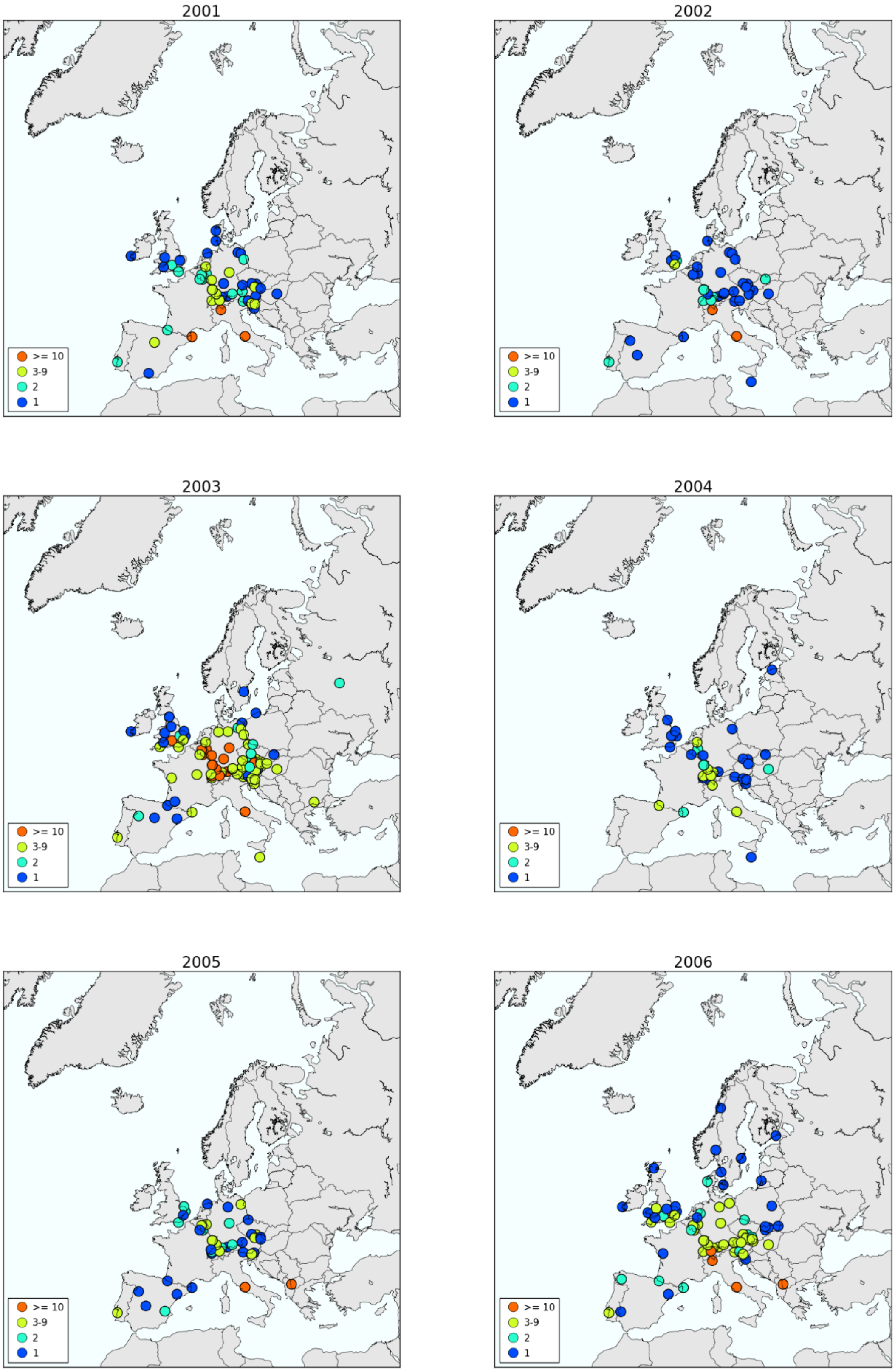


Figure 3: Number of exceedances of the threshold value of 180 μg/m³ 2001-2018. (Unit: number of days.) Stations with zero exceedances are not shown.

Figure 3, cont.:

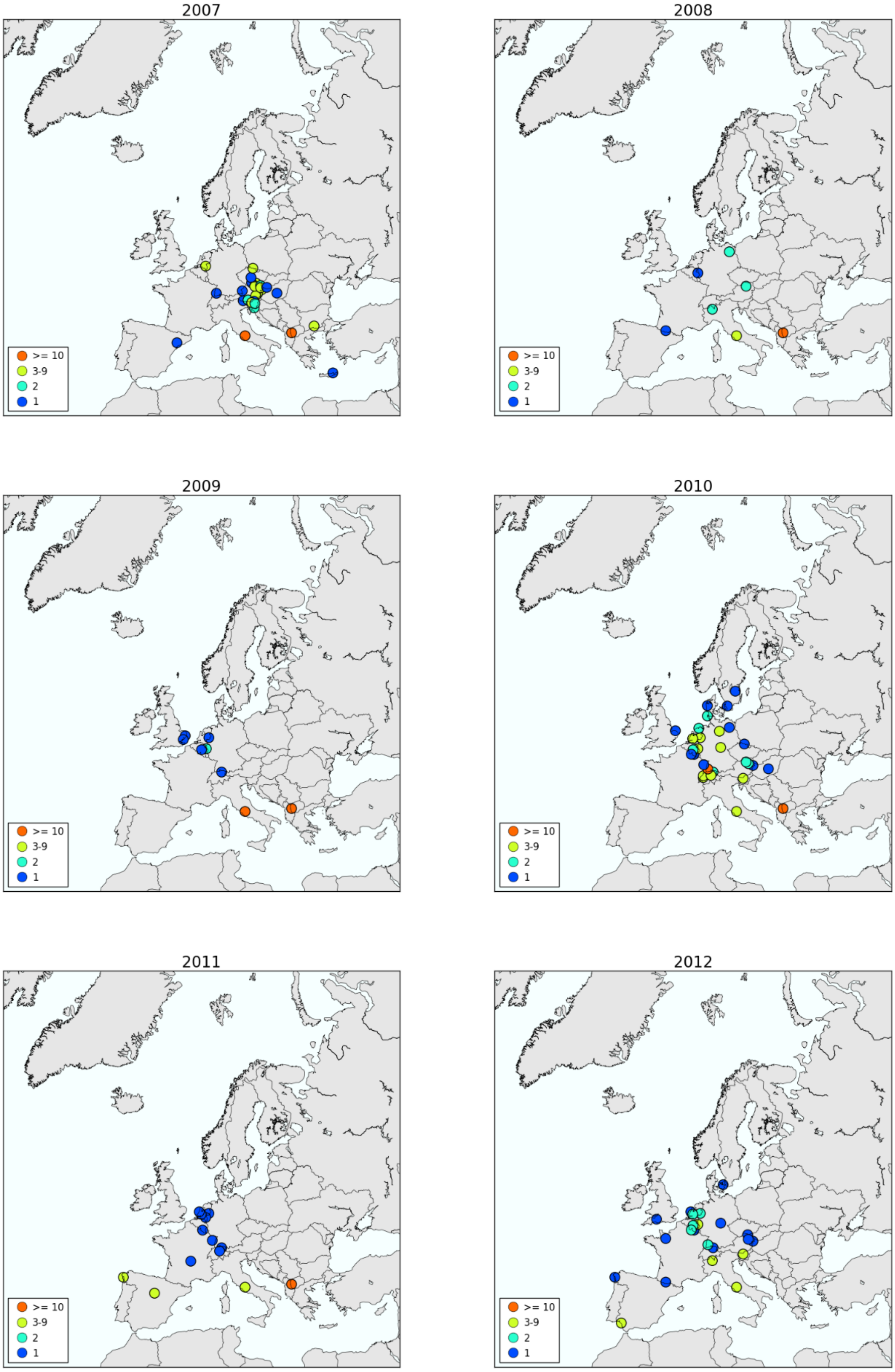
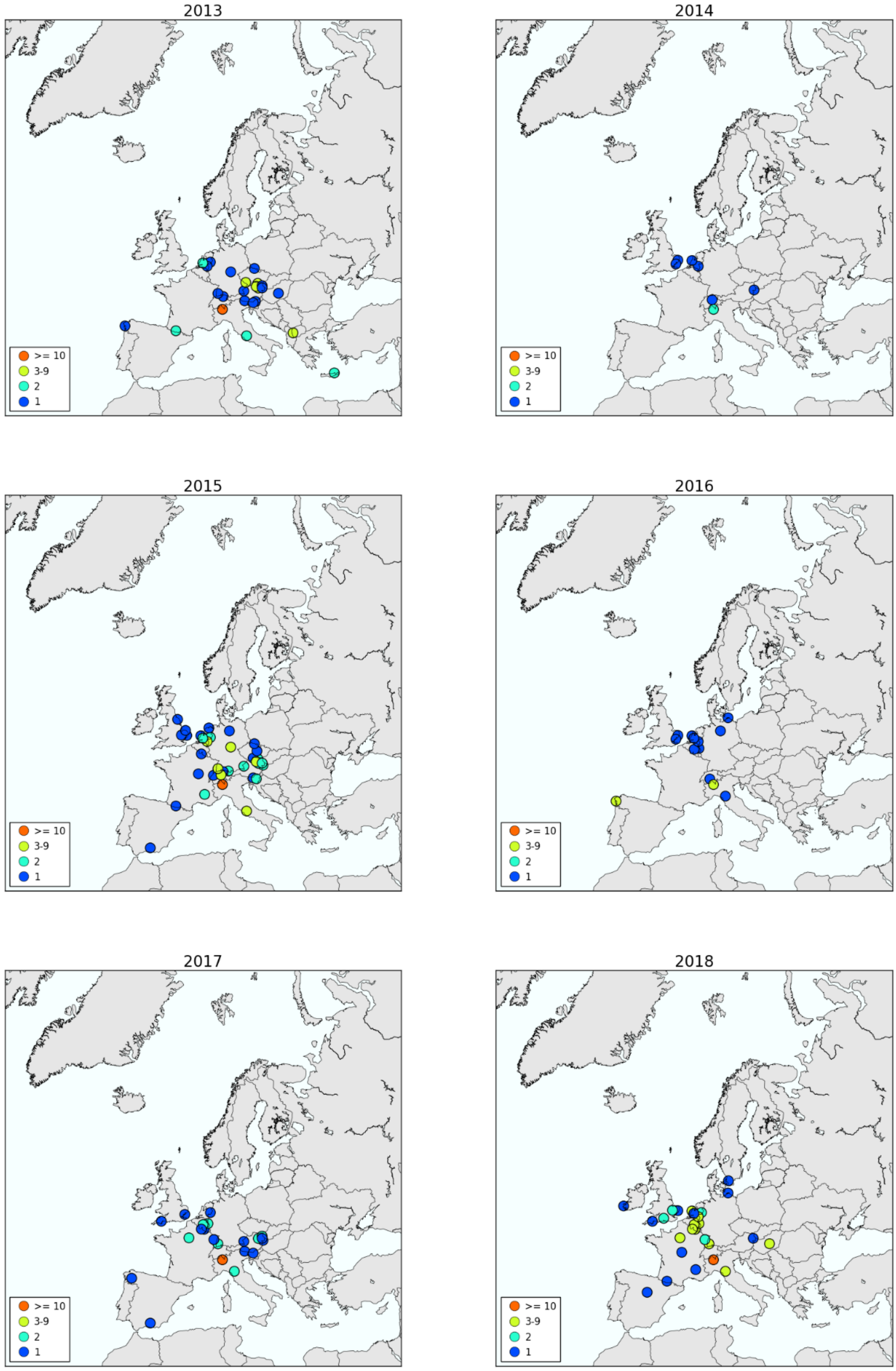


Figure 3, cont.:



6. Calculation of AOT40

AOT40 for forest and agricultural crops for 2018 are shown in Table A.1, Annex 1, and the corresponding geographical distributions of AOT40 are shown in Figure 4 . AOT values are calculated using daylight hours only, based on an estimated global radiation above 50 W/m^2 assuming clear skies. 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.

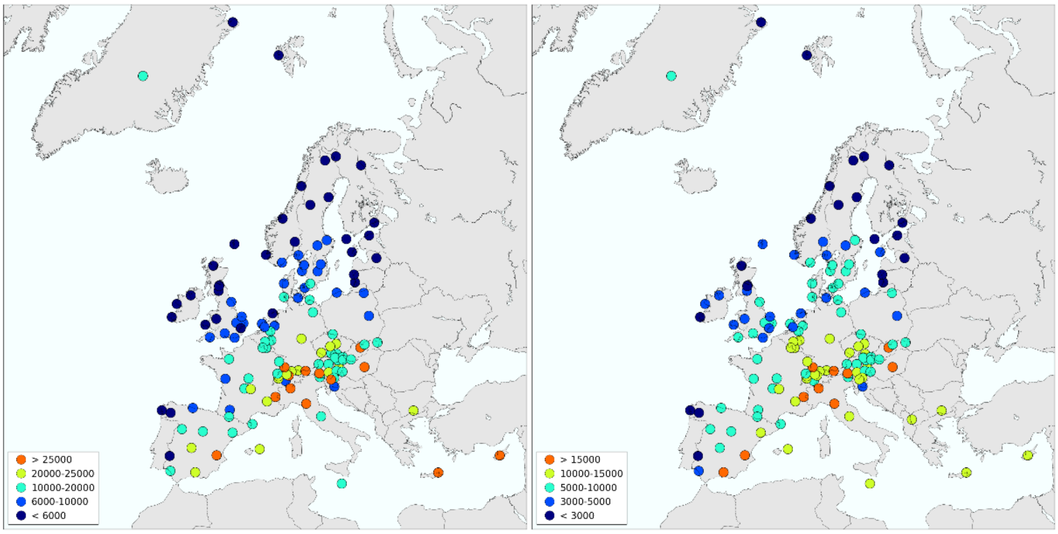


Figure 4: AOT40 April-September (left) and May-July (right) 2018. Unit: ppb hours

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 2020.

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

A large number of co-workers in participating countries have been involved in the many steps of collection of EMEP's measurement data. A list of participating institutes can be seen below. The staff at CCC wishes to express their gratitude and appreciation for continued good co-operation and efforts.

Closer at home the secretarial work, and far beyond, has been performed by Berit Modalen. Ann Mari Fjæraa, Rita Larsen Våler and Mona Waagsbø have been very helpful with data flow and database maintenance.

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	Mines 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 2018

Table A.1: Statistical summary of ozone data 2018.

Station code	Station name	Annual average	Annual Data capture	95-percentil April-September	Maximum concentration Value	Maximum concentration Date	Number of days with values >180	AOT40 April-September	AOT40 May-July
AT0002R	Illmitz	56.7	59.9	129.9	160.6	2018-08-19	0	15897 *	18027 *
AT0005R	Vorhegg	72.1	88.0	122.0	156.0	2018-07-19	0	11425	6184
AT0030R	Pillersdorf bei Retz	68.8	95.3	131.5	172.8	2018-08-23	0	17915	10579
AT0032R	Sulzberg	82.6	94.2	137.5	173.0	2018-07-20	0	21114	12268
AT0034G	Sonnblick	104.0	90.7	140.6	165.6	2018-06-04	0	33523	19381
AT0038R	Gerlitzen	91.8	44.8	139.1	156.6	2018-08-06	0	27263 *	20884 *
AT0040R	Masenberg	84.1	95.0	131.7	154.2	2018-08-21	0	21626	12321
AT0041R	Haunsberg	70.9	95.6	128.7	162.4	2018-04-21	0	14758	8994
AT0042R	Heidenreichstein	64.6	91.2	128.1	165.6	2018-07-05	0	16353	10135 *
AT0043R	Forsthof	72.0	93.2	126.5	155.2	2018-08-20	0	15335	8800
AT0045R	Dunkelsteinerwald	58.5	94.7	127.2	164.8	2018-08-07	0	14249	8366
AT0046R	Gänserndorf	61.3	95.3	127.1	174.6	2018-07-28	0	16309	9628
AT0047R	Stixneusiedl	64.6	94.1	127.7	180.2	2018-08-05	1	15794	9039
AT0048R	Zoebelboden	81.3	93.9	137.3	167.6	2018-08-20	0	18101	9986
AT0049R	Grebenzen bei St. Lamprecht	91.1	94.9	132.5	165.4	2018-04-22	0	21881	11773
AT0050R	Graz Lustbuehel	60.4	93.0	119.5	144.1	2018-04-22	0	11114	6331
BE0001R	Offagne	61.6	95.5	130.0	206.0	2018-08-03	3	15316	10058
BE0032R	Eupen	61.4	94.4	138.5	218.0	2018-08-03	4	17840	12126
BE0035R	Vezin	51.6	94.5	135.0	202.0	2018-08-03	4	15491	10967
BG0053R	Rojen peak	90.1	94.4	124.7	141.8	2018-06-08	0	20485	10320
CH0001G	Jungfraujoch	77.2	96.9	103.3	140.5	2018-06-23	0	7846	5280
CH0002R	Payerne	57.3	98.3	131.0	174.2	2018-08-05	0	20799	11364
CH0003R	Tänikon	58.1	98.1	136.8	176.4	2018-08-06	0	22611	13408
CH0004R	Chaumont	85.3	95.2	142.0	179.2	2018-08-03	0	24453	13258
CH0005R	Rigi	82.7	98.8	142.0	177.1	2018-08-05	0	26057	14831
CH0053R	Beromünster	74.7	98.6	141.4	178.6	2018-08-05	0	24712	14054
CY0002R	Ayia Marina	97.8	92.4	134.3	164.1	2018-05-18	0	30168	14060
CZ0001R	Svratouch	78.1	93.8	133.1	172.2	2018-08-20	0	24733	13764
CZ0003R	Kosetice	69.8	94.5	130.1	174.8	2018-07-05	0	21581	13214

Table A.1, cont.:

Station code	Station name	Annual		95-percentil	Maximum concentration		Number of days with values >180	AOT40	AOT40
		average	Data capture	April-September	Value	Date		April-September	May-July
CZ0003R	Kosetice, Tower inlet height=8.0 m	69.8	94.7	132.0	176.1	2018-07-05	0	22878	14422
CZ0003R	Kosetice, Tower inlet height=50.0 m	77.7	96.1	138.6	177.8	2018-07-05	0	27259	16941
CZ0003R	Kosetice, Tower inlet height=230.0 m	85.8	96.0	145.6	182.0	2018-07-05	1	31140	19358
CZ0005R	Churanov	82.6	95.7	132.5	160.6	2018-07-04	0	24215	13319
DE0001R	Westerland	66.2	87.4	116.9	147.4	2018-08-07	0	10010	7106
DE0002R	Waldhof	58.7	85.2	132.8	177.3	2018-08-09	0	18870 *	13321 *
DE0003R	Schauinsland	92.0	95.9	155.3	204.0	2018-08-05	6	29299	16777
DE0007R	Neuglobsow	57.9	93.0	121.7	176.6	2018-08-08	0	15382	9149
DE0008R	Schmücke	80.3	78.5	138.6	175.4	2018-07-04	0	22865	12976
DE0009R	Zingst	67.1	75.8	115.1	193.0	2018-08-08	1	10246	6556
DE0054R	Schneefernerhaus	104.1	83.6	139.5	167.7	2018-08-01	0	31920	18712
DK0005R	Keldsnor	61.2	87.2	109.8	161.1	2018-07-30	0	6321	4676
DK0010G	Villum Research Station, Station Nord	67.9	84.9	90.1	104.1	2018-05-05	0	797	287
DK0012R	Risoe	63.1	90.1	113.1	168.2	2018-08-08	0	9546	7019
DK0025G	Summit	83.7	97.3	107.4	129.2	2018-06-22	0	10096	6409
DK0031R	Ulborg	60.7	88.6	110.7	160.4	2018-05-30	0	6371	5340
EE0009R	Lahemaa	58.6	99.6	100.8	140.5	2018-05-13	0	4312	2574
EE0011R	Vilsandi	66.4	98.7	109.0	141.0	2018-05-13	0	5965	3754
ES0001R	San Pablo de los Montes	85.7	98.7	123.4	144.4	2018-07-19	0	20874	9916
ES0005R	Noya	68.3	99.3	103.5	147.2	2018-08-03	0	3621	1422
ES0006R	Mahón	84.6	92.0	127.4	172.6	2018-08-04	0	21942	12977
ES0007R	Víznar	85.8	97.6	132.5	164.6	2018-07-26	0	24775	15933
ES0008R	Niembro	76.7	97.4	109.1	168.5	2018-05-06	0	9579	5161
ES0009R	Campisabalos	73.6	96.4	121.2	187.2	2018-07-25	1	17620	8841
ES0010R	Cabo de Creus	76.6	95.1	117.6	154.3	2018-08-05	0	12786	7171
ES0011R	Barcarrota	50.8	97.6	95.4	143.5	2018-09-24	0	3978	514
ES0012R	Zarra	87.8	98.1	130.2	155.1	2018-08-05	0	26896	15040

Table A.1, cont.:

Station code	Station name	Annual		95-percentil	Maximum concentration		Number of days with values >180	AOT40	AOT40
		average	Data capture	April-September	Value	Date		April-September	May-July
ES0013R	Penausende	72.2	97.8	113.1	128.7	2018-08-27	0	12306	5805
ES0014R	Els Torms	74.1	99.1	119.8	154.6	2018-08-06	0	17859	10511
ES0016R	O Saviñao	61.0	98.4	98.1	140.9	2018-09-26	0	4390	1688
ES0017R	Doñana	61.6	97.9	107.7	152.8	2018-08-24	0	10229	4917
FI0009R	Utö	67.6	99.3	102.2	144.7	2018-09-21	0	4143	2492
FI0018R	Virolahti III	55.2	99.2	97.4	137.8	2018-04-15	0	4175	2472
FI0022R	Oulanka	60.5	95.9	100.8	129.8	2018-05-13	0	4189	2241
FI0096G	Pallas (Sammaltunturi)	69.0	99.2	105.6	123.9	2018-04-16	0	4604	2252
FR0008R	Donon	73.2	97.4	139.7	189.6	2018-08-04	2	18178	10555
FR0009R	Revin	68.2	97.5	136.1	207.9	2018-08-03	3	16220	10442
FR0010R	Morvan	66.1	79.8	111.7	159.6	2018-08-06	0	11942 *	5556 *
FR0013R	Peyrusse Vieille	68.8	97.6	111.5	146.7	2018-07-09	0	9793	5066
FR0014R	Montandon	59.8	96.1	123.7	179.6	2018-08-03	0	14478	7446
FR0015R	La Tardière	62.5	97.9	115.9	162.6	2018-08-03	0	9258	5468
FR0016R	Le Casset	96.5	91.4	139.2	167.6	2018-07-17	0	30802	17734
FR0017R	Montfranc	76.6	94.5	123.7	173.6	2018-08-04	0	13830	6987
FR0018R	La Coulonche	68.5	98.8	119.7	153.6	2018-05-07	0	11823	7741
FR0019R	Pic du Midi	91.0	89.6	121.7	207.5	2018-09-24	1	16380	9704
FR0020R	SIRTA Atmospheric Research Observatory	51.0	49.6	174.3	226.0	2018-08-03	4	33542 *	15445 *
FR0023R	Saint-Nazaire-le-Désert	62.7	95.7	129.7	183.6	2018-07-01	1	20076	10628
FR0025R	Verneuil	57.9	99.6	117.1	187.6	2018-08-04	1	12764	6677
FR0030R	Puy de Dôme	90.5	97.0	136.9	177.6	2018-08-04	0	20720	10872
GB0002R	Eskdalemuir	58.2	95.3	97.2	154.4	2018-05-07	0	3970	3164
GB0006R	Lough Navar	50.3	99.2	94.1	179.2	2018-06-28	0	4249	3542
GB0013R	Yarner Wood	64.3	97.4	107.4	185.7	2018-07-02	1	7726	6203
GB0014R	High Muffles	63.5	96.2	107.2	152.4	2018-05-07	0	7637	5456
GB0015R	Strath Vaich Dam	66.3	99.5	95.9	136.3	2018-05-31	0	3904	2556
GB0031R	Aston Hill	65.7	96.7	108.3	154.9	2018-07-01	0	5859	4842

Table A.1, cont.:

Station code	Station name	Annual average	Annual Data capture	95-percentil April-September	Maximum concentration Value	Maximum concentration Date	Number of days with values >180	AOT40 April-September	AOT40 May-July
GB0033R	Bush	58.9	99.1	95.6	134.5	2018-05-07	0	3190	2193
GB0037R	Ladybower Res.	56.0	78.6	94.9	160.9	2018-07-26	0	4140 *	4246 *
GB0038R	Lullington Heath	61.1	99.3	105.3	172.2	2018-07-26	0	6275	4686
GB0039R	Sibton	58.6	98.8	107.5	202.0	2018-07-27	1	8261	6400
GB0043R	Narberth	63.4	99.1	102.9	148.7	2018-05-07	0	4845	3934
GB0045R	Wicken Fen	53.7	99.3	111.2	195.7	2018-07-26	2	9188	7141
GB0048R	Auchencorth Moss	59.0	99.2	93.4	134.4	2018-05-07	0	2894	2163
GB0049R	Weybourne	62.1	99.9	107.5	176.7	2018-07-27	0	6391	4914
GB0050R	St. Osyth	54.5	99.0	100.2	169.3	2018-07-26	0	5238	4245
GB0052R	Lerwick	72.2	85.3	104.6	140.9	2018-06-01	0	5918	3924
GB1055R	Chilbolton Observatory	57.4	98.9	114.3	191.1	2018-07-01	2	9116	7665
GR0001R	Aliartos	67.3	50.5	130.5	158.0	2018-07-19	0	29493 *	15908 *
GR0002R	Finokalia	100.2	98.0	134.4	157.2	2018-07-20	0	29190	14770
HU0002R	K-puszta	70.0	98.7	149.1	204.1	2018-07-25	4	33145	18399
HU0003R	Farkasfa	56.7	97.5	110.8	143.9	2018-08-21	0	10407	5140
IE0001R	Valentia Observatory	67.5	99.7	96.0	203.9	2018-03-11	1	3213	2055
IE0031R	Mace Head	74.7	98.9	104.0	158.6	2018-06-27	0	5751	3978
IT0004R	Ispra	52.2	100.0	149.6	238.1	2018-07-26	11	28761	17211
IT0009R	Mt Cimone	102.5	94.0	143.3	193.8	2018-08-02	3	34892	19342
IT0018R	Lampedusa	92.2	39.1	122.7	156.4	2018-08-24	0	21175 *	13496 *
IT0019R	Monte Martano	84.4	91.7	127.6	163.4	2018-07-14	0	18957	10055
LT0015R	Preila	63.0	97.9	107.9	147.3	2018-09-21	0	5078	2937
LV0010R	Rucava	57.4	85.1	104.7	140.2	2018-09-21	0	4665	2794
LV0016R	Zoseni	58.6	92.5	96.2	131.7	2018-09-21	0	2032	906
MK0007R	Lazaropole	91.5	76.3	132.0	152.0	2018-07-22	0	24348 *	10598
MT0001R	Giordan lighthouse	84.7	85.2	118.8	143.7	2018-06-11	0	18889	11988
NL0007R	Eibergen	45.7	98.4	119.1	189.2	2018-08-07	2	9258	6708
NL0009R	Kollumerwaard	52.0	97.3	105.4	169.3	2018-08-07	0	5611	4295
NL0010R	Vredepeel	48.5	98.4	127.6	205.5	2018-08-03	8	12857	9585
NL0091R	De Zilk	51.9	96.5	111.1	226.7	2018-08-07	3	6834	5308

Table A.1, cont.:

Station code	Station name	Annual		95-percentil	Maximum concentration		Number of days with values >180	AOT40	AOT40
		average	Data capture	April-September	Value	Date		April-September	May-July
NL0644R	Cabauw Wielsekade	44.7	98.4	106.5	195.2	2018-07-27	1	6303	4942
NO0002R	Birkenes II	65.7	97.7	110.3	146.2	2018-06-09	0	7932	5985
NO0015R	Tustervatn	69.6	92.9	108.5	124.0	2018-04-15	0	5550	2205
NO0039R	Kårvatn	56.1	99.2	103.7	123.8	2018-04-13	0	4371	2174
NO0042G	Zeppelin mountain (Ny-Ålesund)	70.8	99.5	93.7	104.9	2018-05-04	0	1933	1097
NO0043R	Prestebakke	61.1	99.2	107.4	144.7	2018-09-18	0	6625	4997
NO0052R	Sandve	65.2	96.8	106.9	146.4	2018-05-31	0	5609	4068
NO0056R	Hurdal	59.7	98.7	105.0	147.8	2018-06-10	0	5398	4134
PL0002R	Jarczew	53.2	99.8	110.7	158.5	2018-07-05	0	7755	4597
PL0003R	Sniezka	80.3	99.9	125.4	165.4	2018-07-06	0	14693	8779
PL0004R	Leba	64.1	99.9	112.4	151.9	2018-06-08	0	7464	4577
PL0005R	Diabla Gora	55.4	98.4	109.5	153.8	2018-06-21	0	8357	5412
RS0005R	Kamenicki vis	70.4	63.4	121.0	142.0	2018-08-25	0	10838 *	3912 *
SE0005R	Bredkälen	63.1	99.6	104.2	127.8	2018-04-17	0	4688	2133
SE0013R	Esrange	69.1	99.8	108.1	127.5	2018-05-15	0	4813	2054
SE0014R	Råö	65.7	99.7	111.5	146.5	2018-06-09	0	7609	6014
SE0018R	Asa	58.7	98.2	109.0	151.0	2018-08-08	0	7746	5544
SE0019R	Östad	58.5	98.6	109.8	147.2	2018-06-08	0	8116	6019
SE0020R	Hallahus	65.4	99.7	114.7	180.2	2018-08-08	1	10801	7579
SE0022R	Norunda Stenen	61.1	78.8	114.8	160.2	2018-04-20	0	9082	5320
SE0032R	Norra-Kvill	68.3	99.5	112.9	157.1	2018-08-08	0	8702	5797
SE0035R	Vindeln	58.6	99.7	105.8	136.0	2018-04-16	0	5223	2575
SE0039R	Grimsö	57.5	98.6	105.6	147.7	2018-04-20	0	6057	4028
SI0008R	Iskrba	51.0	97.8	116.6	161.8	2018-08-03	0	7347	3389
SI0031R	Zarodnje	78.9	94.1	131.1	158.8	2018-08-21	0	19630	10272
SI0032R	Krvavec	94.6	92.8	136.1	165.8	2018-08-06	0	25095	13110
SK0002R	Chopok	95.1	92.6	137.0	173.0	2018-07-06	0	29618	16418
SK0004R	Stará Lesná	67.2	86.3	125.0	151.0	2018-07-24	0	18212	9984
SK0006R	Starina	63.8	92.3	115.0	150.0	2018-07-06	0	11690	5521
SK0007R	Topolniky	54.2	92.8	115.0	144.0	2018-07-24	0	11020	6733

Annex 2

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