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Supplement of

Trends and drivers of ozone human health and vegetation impact metrics from UK EMEP supersite measurements (1990–2013)

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Supplementary information

This supplementary information contains 12 datasheets, summarising the statistics outlined in Section 2 for the derivation of chemical climates relating to the impact of O₃ exposure on human health and on four vegetation types at Harwell (1990-2013) and Auchencorth (2007-2013).

Tables S1 and S2: the chemical climates for the O₃ exposure associated with impact on human health (characterised using the SOMO10 and SOMO35 metrics) for Harwell and Auchencorth respectively.

Tables S3 and S4: the chemical climates for the impact of O₃ on potato (characterised using the POD_Y metric) at Harwell and Auchencorth respectively.

Tables S5 and S6: the chemical climates for the impact of O₃ on wheat (characterised using the POD_Y metric) at Harwell and Auchencorth respectively.

Tables S7 and S8: the chemical climates for the impact of O₃ on crops (characterised using the AOT40 metric) at Harwell and Auchencorth respectively.

Tables S9 and S10: the chemical climates for the impact of O₃ on beech (characterised using the POD_Y metric) at Harwell and Auchencorth respectively.

Tables S11 and S12: the chemical climates for the impact of O₃ on Scots pine (characterised using the POD_Y metric) at Harwell and Auchencorth respectively.

Table S1: Chemical climate datasheet summarising the O₃ exposure associated with human health impact at Harwell.


Impact			State								Drivers							
Acute ozone human health impact Respiratory effects: Increased mortality, decreased lung function, coughing, throat irritation, shortness of breath, inflammation of airways, increased asthma attacks (REVIHAAP, 2013).			No. of exceedance days/year				Ozone Variation (ppb)				Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)							
			SOMO10		SOMO35		Mean		3 rd Quartile		Max		SOMO10		SOMO35			
Metric REVIHAAP (2013) recommends: 1. Assessment of the O ₃ health impact using all year coefficients based on daily maximum 8-hour average O ₃ concentrations. 2. A linear concentration-response relationship for short term exposure 3. 2 thresholds: 10 ppb and 35 ppb Hence health impact evaluated using annual SOMO10 and SOMO35 metrics (sum of max daily 8h means above 10ppb and 35ppb).			1990-1993	312	138	25.0	33.3	111.8	1990-1993	10.8 (2.8)	12.6 (8.7)							
			1994-1997	323	147	24.6	33.3	107.3	1994-1997	10.3 (3.4)	12.3 (8.0)							
			1998-2001	347	143	25.8	33.3	89.3	1998-2001	10.4 (3.4)	12.0 (9.1)							
			2002-2005	346	185	27.3	35.8	88.8	2002-2005	10.8 (3.9)	12.0 (8.8)							
			2006-2009	337	129	25.2	32.8	85.0	2006-2009	10.7 (1.3)	11.9 (9.6)							
			2010-2013	358	148	26.7	33.5	77.9	2010-2013	10.0 (4.0)	11.3 (9.0)							
Years SOMO10 (ppb) SOMO35 (ppb) 1990-1993 8058 1661 1994-1997 8249 1676 1998-2001 8322 1134 2002-2005 9094 1657 2006-2009 7738 985 2010-2013 8512 1088			Seasonal contribution to no. of exceedance days								Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days							
			Spring		Summer		Autumn		Winter		SOMO10		Northerly	Easterly	Southerly	Westerly		
			SOMO10		SOMO35		SOMO10		SOMO35		SOMO10		SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	
			1990-1993	29%	46%	29%	36%	25%	9%	17%	9%	1990-1993	25% (25%)	20% (64%)	28% (9%)	27% (2%)		
			1994-1997	27%	41%	27%	39%	24%	9%	22%	12%	1994-1997	23% (19%)	17% (69%)	21% (8%)	40% (3%)		
			1998-2001	24%	42%	26%	34%	26%	10%	24%	14%	1998-2001	19% (21%)	19% (65%)	26% (6%)	35% (9%)		
			2002-2005	27%	40%	27%	31%	23%	13%	24%	16%	2002-2005	24% (20%)	19% (58%)	21% (20%)	36% (3%)		
			2006-2009	22%	46%	27%	30%	27%	9%	24%	15%	2006-2009	21% (23%)	18% (71%)	23% (3%)	38% (3%)		
			2010-2013	25%	50%	26%	28%	25%	8%	24%	14%	2010-2013	21% (2%)	19% (66%)	19% (32%)	40% (1%)		
			Spring		Summer		Autumn		Winter		SOMO35		Northerly	Easterly	Southerly	Westerly		
			SOMO10		SOMO35		SOMO10		SOMO35		SOMO10		SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	
			1990-1993	34.1%	38.3%	35.8%	52.4%	17.7%	7.9%	12.4%	1.4%	1990-1993	22% (26%)	28% (20%)	27% (28%)	22% (26%)		
			1994-1997	30.6%	31.0%	36.8%	63.4%	16.6%	3.1%	16.1%	2.5%	1994-1997	27% (19%)	15% (24%)	19% (20%)	39% (37%)		
1998-2001	29.0%	41.2%	30.9%	47.0%	20.6%	7.0%	19.4%	4.8%	1998-2001	19% (20%)	19% (21%)	28% (25%)	35% (35%)					
2002-2005	31.6%	43.0%	30.6%	40.1%	19.2%	9.6%	18.6%	7.3%	2002-2005	23% (25%)	19% (20%)	21% (22%)	37% (33%)					
2006-2009	28.7%	46.9%	30.8%	43.3%	21.1%	4.0%	19.5%	5.8%	2006-2009	19% (23%)	22% (18%)	20% (23%)	39% (35%)					
2010-2013	32.7%	56.5%	28.0%	32.1%	19.5%	6.3%	19.9%	5.0%	2010-2013	24% (19%)	19% (20%)	19% (20%)	38% (41%)					
Spatial domain Harwell EMEP level 2 Supersite, lat: 51.571078 long: -1.32528 Temporal Domain O ₃ data: 1990-2013 NO _x data: 1996-2013			Representivity			Mean diurnal variation: SOMO10/35 exceedance (non-exceedance) days (ppb)								Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD _v exceedance (non-exceedance) days (Mg)				
			S and SE UK (Malley et al., 2014a) AURN classification: Rural Background			O ₃		NO		NO ₂		SOMO10		SOMO35				
						SOMO10		SOMO35		SOMO10		SOMO35		SOMO10		SOMO35	SOMO10	
						1990-1993	27.6 (6.9)	36.8 (19.3)	-	-	-	-	1990-1993	57 (138)	67 (61)			
						1994-1997	26.8 (8.1)	34.0 (19.1)	8.9 (55.2)	5.4 (19.1)	14.5 (18.4)	12.1 (16.8)	1994-1997	49 (116)	52 (55)			
						1998-2001	22.8 (8.3)	27.7 (18.9)	6.3 (43.8)	4.6 (9.1)	11.9 (16.0)	10.2 (13.2)	1998-2001	38 (100)	39 (39)			
						2002-2005	24.2 (9.3)	27.5 (19.6)	5.6 (42.0)	3.5 (10.3)	10.8 (15.4)	9.5 (12.5)	2002-2005	35 (91)	35 (39)			
						2006-2009	20.8 (8.6)	24.8 (17.9)	4.4 (38.6)	2.8 (6.9)	9.2 (17.5)	7.6 (10.4)	2006-2009	27 (92)	27 (30)			
						2010-2013	19.9 (9.8)	23.7 (17.0)	4.0 (27.1)	2.5 (5.7)	9.2 (15.0)	7.3 (10.6)	2010-2013	23 (72)	24 (24)			
			Contribution to SOMO10/35 from different daily max 8h concentrations Concentration range (ppb)			90-93		94-97		98-01		02-05		06-09		10-13		
10		35				10		35		10		35		10		35		
10-20 ppb	2%	-				2%	-	2%	-	1%	-	3%	-	2%	-			
20-30 ppb	15%	-				15%	-	18%	-	12%	-	23%	-	18%	-			
30-35 ppb	20%	-				18%	-	24%	-	19%	-	21%	-	24%	-			
35-40 ppb	18%	7%				21%	9%	21%	14%	23%	14%	22%	15%	21%	14%			
40-50 ppb	21%	29%				19%	25%	23%	44%	29%	46%	22%	46%	26%	52%			
50-60 ppb	8%	17%				10%	22%	7%	21%	8%	21%	4%	21%	7%	24%			
60-70 ppb	6%	16%				4%	12%	4%	14%	3%	10%	3%	11%	1%	6%			
>70 ppb	10%	32%				10%	32%	2%	8%	4%	10%	2%	7%	1%	4%			

Table S2: Chemical climate datasheet summarising the O₃ exposure associated with human health impact at Auchencorth.


Impact			State								Drivers								
Acute ozone human health impact Respiratory effects: Increased mortality, decreased lung function, coughing, throat irritation, shortness of breath, inflammation of airways, increased asthma attacks (REVIHAAP, 2013). Metric REVIHAAP (2013) recommends: 1. Assessment of the O ₃ health impact using all year coefficients based on daily maximum 8-hour average O ₃ concentrations. 2. A linear concentration-response relationship for short term exposure 3. 2 thresholds: 10 ppb and 35 ppb Hence health impact evaluated using annual SOMO10 and SOMO35 metrics (sum of max daily 8h means above 10ppb and 35ppb).			No. of exceedance days/year				Ozone Variation (ppb)				Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)								
					SOMO10		SOMO35		Mean		3rd Quartile		Max				SOMO10		SOMO35
			2007		363		166		29.1		35.0		59.0		2007		9.6 (-1.9)		9.1 (9.9)
			2008		361		160		30.1		36.0		71.0		2008		9.0 (-)		9.4 (8.7)
			2009		360		125		27.8		34.0		64.0		2009		9.3 (11.8)		8.5 (9.7)
			2010		365		129		28.1		34.0		70.0		2010		8.1 (-)		9.2 (7.5)
			2011		365		131		28.2		33.0		71.0		2011		9.6 (-)		9.6 (9.6)
			2012		366		123		28.2		33.0		56.0		2012		8.6 (-)		9.1 (8.4)
			2013		364		144		29.8		34.5		54.5		2013		9.0 (-)		8.2 (9.6)
						Seasonal contribution to no. of exceedance days								Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days					
			Spring		Summer		Autumn		Winter				SOMO10	Northerly	Easterly	Southerly	Westerly		
			SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	Northerly	Easterly	Southerly	Westerly		
2007			25%	52%	25%	16%	25%	11%	24%	21%	2007	25% (0%)	17% (100%)	12% (0%)	46% (0%)				
2008			24%	53%	25%	24%	25%	3%	25%	20%	2008	20% (-)	20% (-)	9% (-)	52% (-)				
2009			25%	64%	26%	14%	25%	7%	25%	15%	2009	19% (6%)	22% (0%)	25% (50%)	34% (44%)				
2010			25%	59%	25%	17%	25%	14%	25%	10%	2010	22% (-)	24% (-)	34% (-)	21% (-)				
2011			25%	55%	25%	17%	25%	11%	25%	18%	2011	19% (-)	13% (-)	43% (-)	26% (-)				
2012			25%	63%	25%	24%	25%	4%	25%	9%	2012	20% (-)	18% (-)	28% (-)	34% (-)				
2013			25%	56%	25%	17%	25%	7%	24%	20%	2013	20% (-)	23% (-)	29% (-)	28% (-)				
Years	SOMO10 (ppb)	SOMO35 (ppb)	Spring		Summer		Autumn		Winter		SOMO35	Northerly	Easterly	Southerly	Westerly				
2007	8762	816	SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	2007	24% (26%)	19% (16%)	11% (12%)	46% (46%)				
2008	9111	1379	33%	72%	24%	16%	21%	3%	22%	9%	2008	18% (21%)	28% (13%)	9% (9%)	45% (56%)				
2009	8137	750	35%	74%	24%	16%	19%	1%	22%	9%	2009	16% (21%)	32% (16%)	23% (25%)	28% (37%)				
2010	8517	680	34%	75%	24%	17%	19%	2%	23%	6%	2010	23% (21%)	23% (24%)	34% (33%)	19% (21%)				
2011	8456	676	31%	63%	24%	19%	23%	9%	22%	9%	2011	15% (21%)	16% (11%)	40% (44%)	30% (24%)				
2012	8312	673	32%	66%	23%	16%	22%	10%	24%	9%	2012	25% (17%)	29% (13%)	17% (33%)	28% (37%)				
2013	8820	799	33%	78%	24%	15%	22%	4%	21%	3%	2013	19% (20%)	30% (19%)	29% (29%)	22% (32%)				
2013	8820	799	33%	77%	23%	11%	21%	2%	24%	11%									
Spatial domain		Representivity	Mean diurnal variation: SOMO10/35 exceedance (non-exceedance) days (ppb)								Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD, exceedance (non-exceedance) days (Mg)								
Auchencorth EMEP level 2 Supersite, lat: 55.792160 long: -3.242900 Temporal Domain O ₃ statistics: 2007-2013 NO _x statistics: 2007-2013 (data from proxy site Bush)		Central/northern UK (Malley et al., 2014a) AURN classification: Rural Background 	O₃		NO		NO₂						SOMO10	SOMO35					
			SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35	SOMO10	SOMO35									
			2007	15.7 (10.0)	17.0 (14.7)	3.8 (33.6)	3.6 (4.2)	9.0 (12.8)	8.8 (9.1)	2007	15 (87)	12 (17)							
			2008	16.1 (-)	18.4 (14.3)	3.4 (-)	1.9 (4.7)	8.7 (-)	7.3 (9.9)	2008	16 (-)	14 (17)							
			2009	14.9 (16)	17.6 (13.6)	3.2 (12.8)	2.1 (3.9)	7.9 (11.7)	7.6 (8.1)	2009	14 (17)	14 (14)							
			2010	16.3 (-)	18.8 (15.0)	4.3 (-)	2.3 (5.4)	9.5 (-)	7.6 (10.5)	2010	13 (-)	12 (14)							
			2011	15.4 (-)	18.3 (13.8)	2.6 (-)	1.9 (3.1)	6.9 (-)	5.9 (7.4)	2011	15 (-)	14 (15)							
			2012	14.5 (-)	17.3 (13.1)	2.4 (-)	1.3 (2.8)	7.4 (-)	5.8 (7.9)	2012	12 (-)	12 (13)							
			2013	13.8 (-)	15.2 (12.9)	2.4 (-)	1.6 (2.9)	7.6 (-)	6.8 (8.1)	2013	10 (-)	9 (11)							
						Contribution to SOMO10/35 from different daily max 8h concentrations													
			Concentration range (ppb)	2007		2008		2009		2010		2011		2012		2013			
				10	35	10	35	10	35	10	35	10	35	10	35	10	35		
			10-20 ppb	0%	-	0%	-	1%	-	0%	-	0%	-	1%	-	0%	-		
			20-30 ppb	19%	-	20%	-	28%	-	21%	-	23%	-	26%	-	16%	-		
			30-35 ppb	24%	-	20%	-	23%	-	33%	-	30%	-	28%	-	33%	-		
			35-40 ppb	32%	27%	15%	8%	18%	15%	25%	30%	26%	27%	21%	21%	23%	21%		
			40-50 ppb	21%	58%	32%	56%	27%	72%	19%	60%	17%	55%	22%	67%	25%	71%		
			50-60 ppb	3%	15%	9%	25%	3%	13%	1%	6%	2%	10%	2%	12%	2%	8%		
			60-70 ppb	0%	0%	3%	11%	0%	0%	1%	4%	1%	8%	0%	0%	0%	0%		

Table S3: Chemical climate datasheet summarising the impact of O₃ on potato at Harwell.

Impact			State				Drivers				
Ozone impact on POTATO Critical levels for O ₃ impact on potato based on reduction in tuber size (LRTAP Convention, 2010).			Annual and monthly no. of POD_y exceedance days				Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)				
				annual	5	6	7		5	6	7
Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (1130°C days after plant emergence (26 th May)). Critical level POD ₆ = 2 corresponds to 5% tuber reduction.			1990-1993	27	2	16	8	1990-1993	15.0 (11.7)	15.5 (13.0)	17.3 (16.3)
			1994-1997	25	2	19	3	1994-1997	13.8 (10.2)	15.3 (13.0)	17.9 (17.3)
Annual POD_y 1990-2013 Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			1998-2001	26	3	19	5	1998-2001	14.1 (12.1)	15.3 (13.5)	16.2 (16.7)
			2002-2005	23	3	19	1	2002-2005	14.9 (11.4)	16.2 (14.3)	15.4 (16.7)
			2006-2009	27	2	19	6	2006-2009	14.7 (12.5)	16.0 (14.8)	17.5 (16.9)
			2010-2013	25	2	20	3	2010-2013	15.4 (11.2)	14.9 (13.8)	18.0 (16.8)
			Monthly % contribution to POD_y			Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)					
				5	6	7		5	6	7	
			1990-1993	20%	57%	24%	1990-1993	233 (182)	226 (121)	121 (262)	
			1994-1997	6%	89%	5%	1994-1997	365 (241)	330 (201)	201 (250)	
			1998-2001	10%	87%	3%	1998-2001	271 (185)	239 (151)	151 (216)	
			2002-2005	12%	87%	1%	2002-2005	264 (186)	243 (152)	152 (275)	
			2006-2009	6%	90%	4%	2006-2009	249 (187)	244 (180)	180 (196)	
			2010-2013	9%	86%	5%	2010-2013	310 (233)	259 (191)	191 (311)	
			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) days (ppb)			Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)					
				5	6	7		5	6	7	
			1990-1993	46.5 (35.7)	39.2 (24.0)	39.2 (25.2)	1990-1993	79 (68)	107 (62)	52 (49)	
			1994-1997	36.9 (30.8)	37.0 (23.0)	63.6 (39.2)	1994-1997	55 (61)	52 (35)	67 (47)	
			1998-2001	39.3 (27.0)	32.9 (19.9)	31.7 (27.7)	1998-2001	66 (39)	47 (35)	46 (41)	
			2002-2005	38.8 (23.3)	29.4 (20.5)	26.4 (28.0)	2002-2005	43 (28)	34 (30)	39 (28)	
			2006-2009	32.0 (25.8)	30.8 (23.3)	28.8 (24.4)	2006-2009	42 (31)	45 (34)	23 (24)	
			2010-2013	20.3 (22.6)	22.7 (19.2)	40.2 (21.9)	2010-2013	16 (23)	19 (21)	55 (18)	
Average annual POD_y and % yield reduction			Mean diurnal NO variation: POD_y exceedance (non-exceedance) days (ppb)			Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days					
Averaged period	POD_y (mmol m⁻²)	Yield reduction		5	6	7		Northerly	Easterly	Southerly	Westerly
1990-1993	3.62 ± 1.62	4.7%	1990-1993	-	-	-	1990-1993	22% (28%)	35% (15%)	21% (27%)	22% (29%)
1994-1997	2.87 ± 1.38	3.7%	1994-1997	8.5 (6.0)	4.8 (3.1)	- (3.4)	1994-1997	38% (27%)	6% (13%)	20% (17%)	35% (43%)
1998-2001	2.24 ± 1.35	2.9%	1998-2001	4.5 (5.7)	5.6 (3.8)	8.0 (3.9)	1998-2001	21% (20%)	17% (16%)	27% (27%)	35% (36%)
2002-2005	3.09 ± 2.04	4.0%	2002-2005	3.7 (2.6)	2.2 (1.5)	1.4 (2.7)	2002-2005	23% (26%)	11% (16%)	21% (18%)	45% (40%)
2006-2009	2.15 ± 0.58	2.8%	2006-2009	4.4 (3.9)	3.5 (4.5)	1.9 (2.5)	2006-2009	26% (24%)	25% (14%)	18% (25%)	30% (38%)
2010-2013	1.88 ± 1.07	2.4%	2010-2013	0.9 (2.2)	2.1 (2.0)	2.2 (1.7)	2010-2013	25% (24%)	14% (6%)	21% (19%)	40% (51%)
Spatial domain		Representivity	Mean diurnal NO₂ variation: POD_y exceedance (non-exceedance) days (ppb)								
Harwell EMEP level 2 Supersite, lat: 51.571078 long: -1.32528		S and SE UK (Malley et al., 2014a) AURN classification: Rural Background		5	6	7					
			1990-1993	-	-	-					
Temporal Domain O ₃ data: 1990-2013 NO _x data: 1996-2013			1994-1997	12.7 (11.3)	12.7 (8.6)	- (7.9)					
			1998-2001	9.5 (12.1)	11.7 (8.1)	11.7 (8.6)					
			2002-2005	11.1 (7.7)	7.6 (6.9)	5.6 (7.2)					
			2006-2009	10.9 (8.9)	8.1 (8.2)	3.8 (6.5)					
			2010-2013	4.4 (6.4)	6.5 (6.0)	11.5 (4.9)					

Table S4: Chemical climate datasheet summarising the impact of O₃ on potato at Auchencorth.

Impact			State			Drivers					
Ozone impact on POTATO Critical levels for O ₃ impact on potato based on reduction in tuber size (LRTAP Convention, 2010).			Annual and monthly no. of POD_y exceedance days			Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)					
			Annual	5	6	7	5	6	7		
Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (1130°C days after plant emergence (26 th May)). Critical level POD ₆ = 2 corresponds to 5% tuber reduction.			2007	24	0	11	13	2007	- (10.2)	14.7 (11.6)	14.6 (13.5)
			2008	36	2	22	12	2008	15.3 (11.2)	13.3 (11.5)	15.4 (14.7)
			2009	23	3	13	7	2009	15.6 (10.3)	14.6 (11.8)	17.0 (14.5)
			2010	20	0	17	3	2010	- (10.2)	15.2 (13.8)	16.4 (14.9)
			2011	23	0	9	14	2011	- (10.9)	13.8 (11.7)	14.6 (14.0)
			2012	18	3	11	4	2012	14.8 (8.7)	13.5 (11.1)	15.5 (13.2)
			2013	17	2	14	1	2013	13.6 (9.9)	13.8 (12.6)	17.3 (16.7)
Annual POD_y 2007-2013. Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			Monthly % contribution to POD_y			Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)					
			5	6	7	5	6	7			
			2007	-	80%	20%	2007	- (195)	171 (138)	217 (174)	
			2008	27%	53%	20%	2008	287 (185)	223 (147)	206 (144)	
			2009	20%	39%	42%	2009	295 (208)	230 (206)	221 (171)	
			2010	-	100%	-	2010	- (277)	350 (220)	366 (219)	
			2011	-	30%	70%	2011	- (307)	306 (173)	363 (258)	
2012	50%	47%	3%	2012	499 (269)	313 (217)	248 (234)				
2013	2%	96%	2%	2013	360 (274)	370 (289)	487 (327)				
			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) days (ppb)			Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)					
			5	6	7	5	6	7			
			2007	- (18.0)	27.1 (15.9)	17.1 (16.1)	2007	- (10)	30 (14)	13 (10)	
			2008	44.5 (22.4)	17.4 (21.3)	23.3 (16.1)	2008	36 (19)	11 (13)	21 (16)	
			2009	24.7 (15.5)	19.3 (12.8)	23.7 (12.7)	2009	16 (7)	14 (7)	17 (13)	
			2010	- (20.0)	22.4 (16.5)	19.0 (13.6)	2010	- (8)	14 (12)	7 (8)	
			2011	- (16.0)	20.2 (15.9)	22.1 (15.9)	2011	- (13)	11 (12)	16 (10)	
2012	24.0 (18.7)	18.9 (15.4)	20.5 (13.9)	2012	8 (11)	12 (15)	23 (7)				
2013	23.8 (16.6)	21.3 (16.0)	17.0 (18.9)	2013	6 (9)	12 (8)	5 (11)				
Average annual POD_y and % yield reduction for quartile groups			Mean diurnal NO variation: POD_y exceedance (non-exceedance) days (ppb)			Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days					
			5	6	7	Northerly	Easterly	Southerly	Westerly		
Year	POD _y (mmol m ⁻²)	Yield reduction	2007	- (3.2)	6.6 (5.0)	2.8 (3.5)	2007	24% (33%)	30% (16%)	24% (5%)	22% (46%)
2008	1.1	1.4%	2008	0.8 (3.3)	1.1 (2.0)	3.1 (2.5)	2008	21% (19%)	14% (20%)	10% (14%)	55% (47%)
2009	1.7	2.2%	2009	1.3 (0.6)	3.5 (1.2)	- (0.6)	2009	15% (21%)	52% (13%)	24% (26%)	10% (40%)
2010	1.4	1.7%	2010	- (2.6)	2.0 (2.1)	1.3 (1.4)	2010	21% (19%)	9% (15%)	56% (40%)	14% (26%)
2011	1.0	1.3%	2011	- (1.5)	1.3 (2.1)	1.9 (2.4)	2011	47% (33%)	5% (4%)	34% (34%)	13% (28%)
2012	0.6	0.8%	2012	1.6 (2.8)	1.5 (1.1)	6.4 (0.9)	2012	29% (28%)	23% (11%)	38% (32%)	10% (28%)
2013	0.6	0.8%	2013	1.6 (1.4)	2.0 (1.7)	0.8 (1.5)	2013	25% (19%)	8% (7%)	36% (34%)	31% (40%)
Spatial domain Auchencorth EMEP level 2 Supersite, lat: 55.792160 long: -3.242900		Representivity Central/northern UK (Malley et al., 2014a) AURN classification: Rural Background	Mean diurnal NO₂ variation: POD_y exceedance (non-exceedance) days (ppb)								
			5	6	7						
Temporal Domain O ₃ statistics: 2007-2013 NO _x statistics: 2007-2013 (data from proxy site Bush)			2007	- (8.3)	14.9 (11.1)	5.6 (5.0)					
			2008	8.2 (11.0)	4.9 (7.2)	7.7 (5.8)					
			2009	7.6 (3.8)	9.0 (5.7)	- (3.7)					
			2010	- (7.8)	6.4 (7.1)	3.2 (3.8)					
			2011	- (3.8)	4.0 (5.5)	5.4 (6.3)					
			2012	5.3 (8.4)	4.9 (5.2)	10.2 (3.8)					
			2013	5.6 (6.5)	6.3 (4.9)	1.6 (5.9)					

Table S5: Chemical climate datasheet summarising the impact of O₃ on wheat at Harwell.

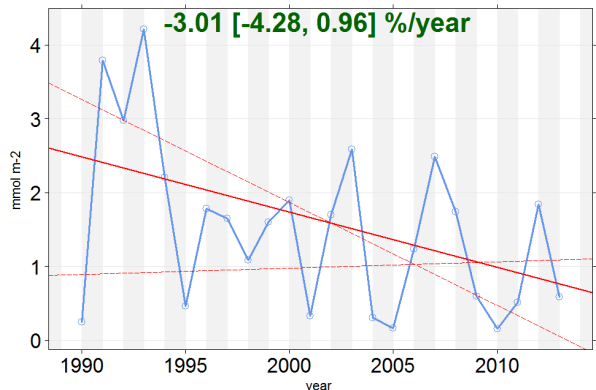

Impact			State			Drivers							
Ozone impact on WHEAT Critical levels for O ₃ impact on wheat based on reduction in grain yield (LRTAP Convention, 2010).			Annual and monthly no. of POD_y exceedance days			Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)							
			Annual	6	7	6	7						
Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (200°C before anthesis - 700°C after anthesis). Critical level POD ₆ = 1 corresponds to 5% yield reduction.			1990-1993	24	14	10	1990-1993	15.4 (13.5)	17.4 (16.4)				
			1994-1997	18	13	5	1994-1997	15.1 (13.6)	17.9 (17.2)				
			1998-2001	20	14	7	1998-2001	15.2 (14.0)	16.4 (16.6)				
			2002-2005	15	11	4	2002-2005	16.5 (15.1)	16.3 (16.7)				
			2006-2009	22	14	8	2006-2009	15.7 (15.4)	17.5 (16.8)				
			2010-2013	19	15	4	2010-2013	14.2 (14.4)	16.4 (17.0)				
Annual POD_y 1990-2013 Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			Monthly % contribution to POD_y			Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)							
			6	7	6	7							
			1990-1993	74%	26%	1990-1993	228 (147)	251 (158)					
			1994-1997	83%	17%	1994-1997	324 (238)	224 (252)					
			1998-2001	90%	10%	1998-2001	236 (177)	214 (199)					
			2002-2005	92%	8%	2002-2005	236 (187)	222 (180)					
			2006-2009	90%	10%	2006-2009	233 (213)	190 (199)					
			2010-2013	97%	3%	2010-2013	247 (222)	279 (258)					
Average annual POD_y and % yield reduction			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) days (ppb)			Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)							
			6	7	6	7							
			1990-1993	40.5 (27.3)	38.2 (26.5)	1990-1993	122 (59)	52 (53)					
			1994-1997	35.6 (27.0)	58.9 (26.7)	1994-1997	53 (39)	76 (43)					
			1998-2001	31.9 (24.7)	29.5 (26.6)	1998-2001	49 (38)	43 (40)					
			2002-2005	29.2 (26.2)	35.0 (26.7)	2002-2005	34 (35)	35 (26)					
2006-2009	27.0 (30.0)	29.9 (24.0)	2006-2009	40 (41)	28 (23)								
2010-2013	20.9 (20.8)	27.4 (22.7)	2010-2013	17 (21)	16 (20)								
Averaged period POD_y (mmol m⁻²) Yield reduction			Mean diurnal NO variation: POD_y exceedance (non-exceedance) days (ppb)			Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days							
			6	7	Northerly	Easterly	Southerly	Westerly					
			1990-1993	2.81 ± 1.78	10.7%	1990-1993	-	-	28% (27%)	33% (25%)	21% (23%)	19% (25%)	
			1994-1997	1.53 ± 0.74	5.8%	1994-1997	5.1 (3.6)	2.8 (3.1)	1994-1997	37% (30%)	3% (16%)	15% (21%)	45% (33%)
			1998-2001	1.23 ± 0.60	4.7%	1998-2001	5.6 (4.7)	5.4 (3.7)	1998-2001	23% (23%)	13% (24%)	28% (23%)	35% (29%)
			2002-2005	1.19 ± 1.16	4.5%	2002-2005	1.4 (2.0)	3.5 (2.5)	2002-2005	18% (29%)	15% (13%)	30% (14%)	37% (44%)
2006-2009	1.52 ± 0.80	5.8%	2006-2009	3.9 (4.2)	2.1 (2.5)	2006-2009	33% (18%)	11% (27%)	23% (21%)	22% (16%)			
2010-2013	0.77 ± 0.74	2.9%	2010-2013	1.7 (2.3)	2.9 (1.7)	2010-2013	27% (27%)	13% (16%)	33% (33%)	38% (41%)			
Spatial domain			Representivity			Mean diurnal NO₂ variation: POD_y exceedance (non-exceedance) days (ppb)							
Harwell EMEP level 2 Supersite, lat: 51.571078 long: -1.32528			S and SE UK (Malley et al., 2014a) AURN classification: Rural Background										
Temporal Domain O ₃ data: 1990-2013 NO _x data: 1996-2013													

Table S6: Chemical climate datasheet summarising the impact of O₃ on wheat at Auchencorth.

Impact			State			Drivers				
Ozone impact on WHEAT Critical levels for O ₃ impact on wheat based on reduction in grain yield (LRTAP Convention, 2010).			Annual and monthly no. of POD_y exceedance days			Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)				
				Annual	6	7		6	7	
Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (200°C before anthesis - 700°C after anthesis). Critical level POD ₆ = 1 corresponds to 5% yield reduction.			2007	33	11	22	2007	14.3 (11.8)	14.3 (13.2)	
			2008	40	23	17	2008	13.2 (11.7)	15.4 (14.6)	
			2009	29	14	15	2009	13.6 (12.4)	15.9 (14.3)	
			2010	22	15	7	2010	15.4 (13.8)	16.2 (14.6)	
			2011	31	10	21	2011	12.9 (12.1)	14.5 (13.6)	
			2012	22	15	7	2012	13.0 (11.0)	15.2 (13.0)	
			2013	13	12	1	2013	13.8 (12.8)	17.3 (16.7)	
Annual POD_y 2007-2013 Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			Monthly % contribution to POD_y			Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)				
				6	7		6	7		
			2007	61%	39%	2007	179 (134)	209 (148)		
			2008	64%	36%	2008	219 (147)	187 (144)		
			2009	42%	58%	2009	217 (214)	211 (155)		
			2010	90%	10%	2010	332 (261)	270 (223)		
			2011	20%	80%	2011	271 (184)	355 (200)		
			2012	80%	20%	2012	320 (184)	253 (230)		
2013	99%	1%	2013	354 (309)	487 (327)					
Average annual POD_y and % yield reduction			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) days (ppb)			Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)				
				6	7		6	7		
			2007	27.0 (16.0)	16.9 (15.6)	2007	23 (18)	12 (10)		
			2008	17.0 (23.0)	20.4 (17.0)	2008	10 (15)	21 (15)		
			2009	18.2 (13.3)	17.5 (13.0)	2009	13 (7)	12 (15)		
			2010	19.1 (21.2)	17.3 (13.3)	2010	11 (16)	6 (8)		
			2011	17.5 (17.1)	20.8 (14.2)	2011	11 (12)	15 (9)		
2012	18.3 (15.1)	17.6 (13.9)	2012	13 (15)	15 (8)					
2013	20.8 (16.9)	17.0 (18.9)	2013	13 (8)	5 (11)					
Mean diurnal NO variation: POD_y exceedance (non-exceedance) days (ppb)			Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days							
				6	7		Northerly	Easterly	Southerly	Westerly
			2007	8.1 (4.2)	3.2 (2.8)	2007	35% (25%)	23% (31%)	17% (7%)	25% (36%)
			2008	1.1 (2.1)	2.5 (3.0)	2008	25% (20%)	12% (39%)	10% (15%)	53% (26%)
			2009	1.3 (2.3)	0.3 (0.8)	2009	33% (13%)	33% (26%)	20% (25%)	14% (37%)
			2010	1.9 (2.3)	0.9 (1.5)	2010	19% (22%)	2% (14%)	55% (37%)	25% (27%)
			2011	1.2 (2.2)	2.1 (2.3)	2011	56% (25%)	4% (18%)	27% (32%)	14% (25%)
2012	1.4 (1.0)	3.8 (1.1)	2012	38% (41%)	17% (24%)	34% (16%)	11% (20%)			
2013	1.7 (1.9)	0.8 (1.5)	2013	11% (25%)	23% (10%)	40% (32%)	26% (34%)			
Spatial domain Auchencorth EMEP level 2 Supersite, lat: 55.792160 long: -3.242900		Representivity Central/northern UK (Malley et al., 2014a) AURN classification: Rural Background		Mean diurnal NO₂ variation: POD_y exceedance (non-exceedance) days (ppb)						
Temporal Domain O ₃ statistics: 2007-2013 NO _x statistics: 2007-2013 (data from proxy site Bush)					6					7
				2007	14.5 (11.4)					5.3 (5.3)
				2008	5.0 (7.0)					7.0 (5.9)
				2009	6.2 (7.0)					2.2 (5.1)
				2010	5.5 (8.0)	2.4 (4.2)				
2011	3.9 (5.6)	5.7 (6.2)								
2012	4.7 (5.5)	6.5 (4.1)								
2013	6.2 (5.1)	1.6 (5.9)								

Table S7: Chemical climate datasheet summarising the impact of O₃ on crops at Harwell using the AOT40 metric.


Impact		State			Drivers				
<p>Ozone impact on crops</p> <p>Impact of O₃ crops and wild plants are summarised in (Royal Society, 2008), and include decreased crop yields, nutritional quality, tree growth and photosynthesis rates.</p> <p>Metric: AOT40 Accumulated annual exposure of hourly O₃ concentrations over a threshold of 40 ppb. Gothenburg Protocol 1999 sets long term critical value for the protection of crops at 3000 ppb.h for the sum of daylight hourly concentrations between May and July (typical growing season).</p>		Monthly contribution to AOT40			Meteorology: Monthly average temperature (°C)				
			May	June	July		May	June	July
		1990-1993	32%	31%	37%	1990-1993	12.2	14.4	16.7
		1994-1997	28%	27%	45%	1994-1997	10.6	14.4	17.4
		1998-2001	38%	36%	26%	1998-2001	12.5	14.6	16.5
		2002-2005	39%	31%	30%	2002-2005	11.8	15.6	16.7
		2006-2009	38%	36%	26%	2006-2009	12.6	15.4	17.2
		2010-2013	44%	21%	35%	2010-2013	11.5	14.5	17.1
		Monthly average diurnal O₃ cycle (ppb)			Air Mass origin: Percentage of trajectories from 4 geographical groupings during growing season (May-July)				
			May	June	July		Northerly	Easterly	Southerly
1990-1993	26.8	22.9	23.8	1990-1993	27%	27%	14%	32%	
1994-1997	22.5	22.5	30.4	1994-1997	32%	13%	20%	35%	
1998-2001	17.3	18.2	20.8	1998-2001	23%	23%	24%	30%	
2002-2005	15.5	19.5	21.3	2002-2005	29%	11%	15%	45%	
2006-2009	16.5	20.6	20.3	2006-2009	21%	25%	17%	38%	
2010-2013	15.7	14.7	18.8	2010-2013	28%	15%	17%	40%	
Averaging period	AOT40 (ppb.h)	Monthly average diurnal NO cycle (ppb)			Emissions: Average hourly emissions along 96 hour back trajectory path during each month of growing season (Mg)				
			May	June	July		May	June	July
1990-1993	6533	1990-1993	-	-	-	1990-1993	70.6	78.3	53.8
1994-1997	6463	1994-1997	3.4	2.3	2.7	1994-1997	61.6	46.5	49.6
1998-2001	3483	1998-2001	2.9	2.4	1.8	1998-2001	41.9	42.3	40.8
2002-2005	3688	2002-2005	1.7	0.9	1.6	2002-2005	29.6	32.7	28.3
2006-2009	3433	2006-2009	1.9	1.8	1.5	2006-2009	30.1	39.1	22.0
2010-2013	2623	2010-2013	1.6	1.1	1.4	2010-2013	22.6	19.7	21.4
Spatial domain	Representivity	Monthly average diurnal NO₂ cycle (ppb)			Annual crop AOT40 1990-2013				
			May	June	July	<p>Theil Sen trend estimate is significant ($p = 0.001$)</p>			
Harwell	S and SE UK (Malley et al., 2014a)	1990-1993	-	-	-				
EMEP level 2 Supersite, lat: 51.571078	AURN classification: Rural Background	1994-1997	4.1	5.0	4.4				
long: -1.32528		1998-2001	5.2	4.4	3.8				
Temporal Domain		2002-2005	3.2	2.9	2.5				
O ₃ data: 1990-2013		2006-2009	2.6	2.7	2.2				
NO _x data: 1996-2013)		2010-2013	2.8	2.5	2.3				

Table S8: Chemical climate datasheet summarising the impact of O₃ on crops at Auchencorth using the AOT40 metric.


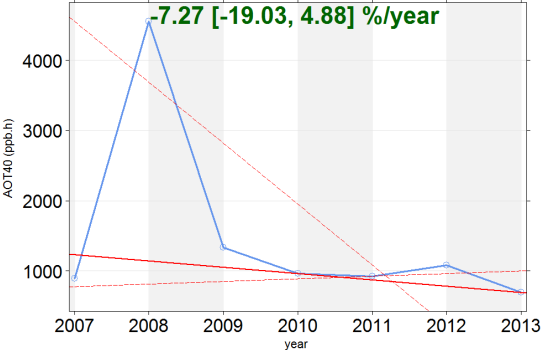
Impact		State			Drivers					
<p>Ozone impact on crops</p> <p>Impact of O₃ crops and wild plants are summarised in (Royal Society, 2008), and include decreased crop yields, nutritional quality, tree growth and photosynthesis rates.</p> <p>Metric: AOT40</p> <p>Accumulated annual exposure of hourly O₃ concentrations over a threshold of 40 ppb. Gothenburg Protocol 1999 sets long term critical value for the protection of crops at 3000 ppb.h for the sum of daylight hourly concentrations between May and July (typical growing season).</p>		Monthly contribution to AOT40			Meteorology: Monthly average temperature (°C)					
			May	June	July		May	June	July	
		2007	42%	57%	1%	2007	10.2	12.7	14.0	
		2008	82%	11%	7%	2008	11.4	12.9	15.0	
		2009	57%	23%	20%	2009	11.0	13.1	15.3	
		2010	39%	61%	0%	2010	10.2	14.5	15.0	
		2011	61%	10%	30%	2011	10.9	12.5	14.3	
		2012	96%	3%	1%	2012	9.3	12.0	13.5	
		2013	73%	13%	14%	2013	10.1	13.2	16.8	
		<p>Years</p> <p>AOT40 (ppb.h)</p> <p>2007 896</p> <p>2008 4555</p> <p>2009 1332</p> <p>2010 963</p> <p>2011 925</p> <p>2012 1085</p> <p>2013 694</p>		Monthly average diurnal O₃ cycle (ppb)			Air Mass origin: Percentage of trajectories from 4 geographical groupings during growing season (May-July)			
	May			June	July		Northerly	Easterly	Southerly	Westerly
2007	8.4			7.4	10.2	2007	27%	32%	11%	30%
2008	14.0			12.0	11.3	2008	22%	32%	12%	34%
2009	10.1			11.4	10.8	2009	19%	31%	20%	30%
2010	12.7			13.8	7.0	2010	20%	14%	43%	24%
2011	8.7			10.6	13.7	2011	34%	11%	32%	23%
2012	11.4			8.4	8.0	2012	40%	24%	17%	19%
2013	7.0			11.2	11.9	2013	24%	13%	31%	32%
<p>Spatial domain</p> <p>Auchencorth EMEP level 2 Supersite, lat: 55.792160 long: -3.242900</p> <p>Temporal Domain</p> <p>O₃ statistics: 2007-2013 NO_x statistics: 2007-2013 (data from proxy site Bush)</p>				Monthly average diurnal NO_x cycle (ppb)			Emissions: Av. hourly emissions along 96 hour back trajectory path arriving on POD_v exceedance (non-exceedance) days (Mg)			
			May	June	July		May	June	July	
		2007	1.9	3.5	1.7	2007	9.7	19.9	11.2	
		2008	1.5	0.5	1.4	2008	20.4	11.6	18.1	
		2009	0.3	1.1	0.3	2009	7.8	10.1	13.5	
		2010	1.6	1.1	0.8	2010	8.0	13.5	7.6	
		2011	0.8	1.3	1.5	2011	13.4	11.7	13.1	
		2012	2.0	0.8	1.1	2012	10.4	13.9	9.3	
		2013	0.7	1.2	1.0	2013	8.4	9.9	10.5	
		<p>Representivity</p> <p>Central/northern UK (Malley et al., 2014a) AURN classification: Rural Background</p> 		Monthly average diurnal NO_x cycle (ppb)			<p>Annual crop AOT40 1990-2013</p> <p>Theil Sen trend estimate is not statistically significant ($p = 0.05$)</p> 			
	May	June	July		May	June	July			
2007	3.3	3.5	2.1	2007	9.7	19.9	11.2			
2008	4.3	1.2	2.3	2008	20.4	11.6	18.1			
2009	1.5	2.9	1.4	2009	7.8	10.1	13.5			
2010	2.6	2.0	1.5	2010	8.0	13.5	7.6			
2011	0.9	1.6	1.9	2011	13.4	11.7	13.1			
2012	3.8	1.6	1.6	2012	10.4	13.9	9.3			
2013	2.2	1.8	2.0	2013	8.4	9.9	10.5			

Table S9: Chemical climate datasheet summarising the impact of O₃ on beech at Harwell.

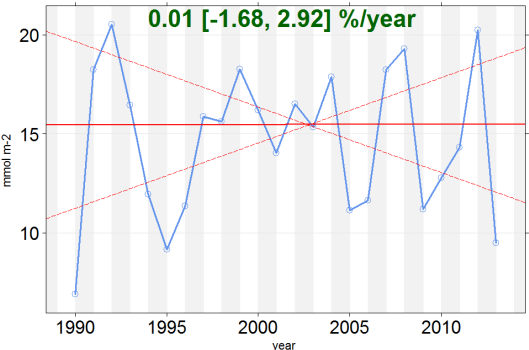

Impact			State							Drivers						
Ozone impact on BEECH Critical levels for O ₃ impact on beech based on reduction in whole tree biomass (LRTAP Convention, 2010).			No. of POD_y exceedance days & monthly contribution							Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)						
Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (19 th April-20 th October). Critical level POD ₁ = 4 corresponds to 4% biomass reduction.			Annual	4	5	6	7	8	9	4	5	6	7	8	9	
90-93			154	8	29	29	27	26	25	90-93	9.8 (7.9)	11.9 (11.2)	14.5 (12.9)	17.0 (15.3)	16.8 (15.6)	13.5 (11.3)
94-97			148	8	27	28	29	24	20	94-97	10.4 (7.3)	10.7 (5.4)	14.5 (-)	17.4 (17.9)	18.0 (18.0)	12.1 (14.3)
98-01			170	8	30	30	30	30	30	98-01	9.9 (6.5)	12.4 (-)	14.6 (-)	16.7 (-)	16.5 (14.3)	14.6 (11.8)
02-05			166	10	31	30	31	30	29	02-05	10.9 (8.2)	11.8 (-)	15.6 (-)	16.7 (14.1)	17.4 (17.6)	14.5 (14.5)
06-09			165	8	29	29	30	30	29	06-09	10.6 (8.2)	12.7 (-)	15.6 (-)	17.2 (16.4)	16.2 (17.6)	14.3 (14.5)
10-13			162	8	31	29	29	29	28	10-13	10.6 (8.4)	11.5 (-)	14.6 (-)	16.9 (18.9)	16.3 (16.4)	13.9 (13.1)
Annual POD_y 1990-2013 Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			Monthly % contribution to POD_y							Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)						
			4	5	6	7	8	9	4	5	6	7	8	9		
90-93			3%	33%	23%	16%	16%	7%	90-93	150 (138)	194 (9)	198 (11)	209 (39)	185 (83)	130 (24)	
94-97			3%	35%	34%	12%	7%	8%	94-97	221 (192)	257 (-)	278 (-)	269 (159)	247 (180)	151 (82)	
98-01			3%	27%	28%	15%	14%	11%	98-01	170 (112)	194 (-)	206 (-)	206 (-)	182 (35)	119 (9)	
02-05			3%	34%	30%	13%	11%	9%	02-05	161 (154)	193 (-)	211 (-)	190 (57)	177 (155)	135 (36)	
06-09			3%	29%	29%	15%	13%	9%	06-09	173 (148)	190 (-)	224 (-)	211 (147)	164 (177)	131 (24)	
10-13			3%	33%	25%	12%	12%	14%	10-13	166 (141)	242 (-)	239 (-)	269 (221)	251 (135)	146 (60)	
Average annual POD_y and % yield reduction for quartile groups			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) (ppb)							Emissions: Average hourly NO_x emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)						
Averaged period	POD_y (mmol m⁻²)	Biomass reduction	4	5	6	7	8	9	4	5	6	7	8	9		
1990-1993	15.5 ± 6.0	17.1%	90-93	31.5 (24.0)	36.7 (14.9)	33.7 (21.5)	33.6 (8.8)	36.4 (13.1)	31.5 (10.8)	90-93	74 (55)	68 (106)	81 (69)	55 (33)	58 (35)	68 (66)
1994-1997	12.0 ± 2.8	13.3%	94-97	28.6 (27.9)	32.2 (2.5)	32.4 (-)	40.6 (22.0)	42.5 (17.7)	24.1 (14.8)	94-97	49 (61)	60 (65)	47 (-)	49 (19)	59 (36)	38 (54)
1998-2001	16.0 ± 3.3	17.6%	98-01	28.5 (21.9)	28.1 (-)	27.9 (-)	28.1 (-)	30.0 (13.5)	24.5 (6.0)	98-01	38 (45)	41 (-)	42 (-)	43 (-)	40 (28)	43 (21)
2002-2005	15.2 ± 2.9	16.7%	02-05	26.7 (29.5)	25.2 (-)	26.8 (-)	28.2 (17.0)	32.5 (15.8)	28.9 (13.3)	02-05	47 (45)	30 (-)	33 (-)	28 (39)	38 (33)	40 (25)
2006-2009	15.1 ± 4.3	16.6%	06-09	24.6 (24.5)	26.2 (-)	28.4 (-)	24.8 (11.0)	20.5 (19.0)	21.0 (5)	06-09	31 (30)	32 (-)	40 (-)	22 (6)	19 (22)	29 (15)
2010-2013	14.2 ± 4.5	15.6%	10-13	22.6 (18.5)	22.8 (-)	21.4 (-)	24.1 (16.9)	21.6 (15.6)	19 (13)	10-13	28 (27)	23 (-)	19 (-)	22 (8)	17 (9)	19 (25)
Spatial domain Harwell EMEP level 2 Supersite, lat: 51.571078 long: -1.325283			Mean diurnal NO variation: POD_y exceedance (non-exceedance) (ppb)							Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days						
Representivity S and SE UK (Malley et al., 2014a) AURN classification: Rural Background			4	5	6	7	8	9	Northerly	Easterly	Southerly	Westerly				
Temporal Domain O ₃ data: 1990-2013 NO _x data: 1996-2013			90-93	-	-	-	-	-	90-93	28% (29%)	23% (18%)	25% (27%)	24% (27%)			
			94-97	9.7 (18.4)	11.6 (-)	11.2 (-)	7.9 (-)	-	94-97	29% (23%)	15% (22%)	20% (21%)	36% (34%)			
			98-01	10.0 (10.3)	11.9 (-)	10.2 (-)	8.8 (-)	11.1 (11.7)	10.5 (-)	98-01	19% (20%)	20% (17%)	27% (35%)	33% (28%)		
			02-05	11.0 (12.7)	8.2 (-)	7.3 (-)	7.0 (9.0)	13.2 (11.8)	11.8 (9.7)	02-05	27% (19%)	16% (42%)	18% (20%)	39% (19%)		
			06-09	9.0 (8.2)	9.0 (-)	8.1 (-)	6.1 (2.1)	4.6 (9.0)	9.0 (6.6)	06-09	21% (28%)	20% (15%)	22% (22%)	37% (35%)		
			10-13	7.5 (6.5)	6.3 (-)	6.3 (-)	5.4 (5.0)	6.5 (7.8)	7.8 (5.6)	10-13	20% (15%)	15% (16%)	19% (20%)	43% (41%)		

Table S10: Chemical climate datasheet summarising the impact of O₃ on beech at Auchencorth.

Impact			State					Drivers							
Ozone impact on BEECH Critical levels for O ₃ impact on beech based on reduction in whole tree biomass (LRTAP Convention, 2010).			Annual and monthly no. of POD_y exceedance days					Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)							
			Annual	5	6	7	8	9		5	6	7	8	9	
Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (26 th April-10 th October). Critical level POD ₁ = 4 corresponds to 4% biomass reduction.			2007	159	31	30	31	31	30	2007	10.2 (-)	12.7 (-)	14.0 (-)	14.1 (-)	12.6 (-)
			2008	157	31	30	31	31	30	2008	11.4 (-)	12.8 (-)	15.0 (-)	14.9 (-)	12.4 (-)
			2009	156	29	30	31	31	29	2009	10.9 (-)	13.0 (-)	15.1 (-)	15.5 (-)	13.3 (10.4)
			2010	160	31	30	31	31	30	2010	10.2 (-)	14.7 (-)	15.0 (-)	14.0 (-)	12.9 (-)
			2011	155	31	28	31	31	30	2011	10.9 (-)	12.3 (13.4)	14.2 (-)	13.7 (-)	13.5 (-)
			2012	155	31	30	29	31	30	2012	9.3 (-)	12.0 (-)	13.6 (11.0)	14.8 (-)	11.8 (-)
			2013	155	31	30	31	31	29	2013	10.1 (-)	13.2 (-)	16.8 (-)	15.3 (-)	12.5 (13.6)
Annual POD_y 2007-2013. Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			Monthly % contribution to POD_y					Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)							
			5	6	7	8	9		5	6	7	8	9		
			2007	21%	23%	23%	19%	14%	2007	195 (-)	150 (-)	192 (-)	208 (-)	117 (-)	
			2008	30%	25%	21%	15%	9%	2008	192 (-)	202 (-)	168 (-)	122 (-)	94 (-)	
			2009	25%	25%	22%	18%	10%	2009	217 (-)	216 (-)	182 (-)	231 (-)	154 (116)	
			2010	21%	27%	19%	19%	15%	2010	277 (-)	299 (-)	234 (-)	215 (-)	156 (-)	
			2011	25%	21%	26%	14%	14%	2011	307 (-)	223 (-)	305 (-)	190 (-)	183 (-)	
			2012	25%	23%	18%	21%	13%	2012	291 (-)	252 (-)	230 (388)	232 (-)	178 (-)	
			2013	25%	28%	15%	22%	10%	2013	280 (-)	327 (-)	333 (-)	232 (-)	106 (27)	
Average annual POD_y and % yield reduction for quartile groups			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) (ppb)					Emissions: Average hourly NO_x emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)							
			5	6	7	8	9		5	6	7	8	9		
			2007	18.0 (-)	20.0 (-)	16.5 (-)	16.8 (-)	13.4 (-)	2007	10 (-)	20 (-)	11 (-)	8 (-)	6 (-)	
			2008	23.8 (-)	18.4 (-)	18.9 (-)	15.7 (-)	16.0 (-)	2008	20 (-)	12 (-)	18 (-)	16 (-)	23 (-)	
			2009	16.4 (-)	15.5 (-)	15.2 (-)	13.3 (-)	13.1 (5)	2009	8 (-)	10 (-)	13 (-)	7 (-)	7 (18)	
			2010	20.0 (-)	20.1 (-)	14.2 (-)	15.6 (-)	16.8 (-)	2010	8 (-)	13 (-)	8 (-)	6 (-)	14 (-)	
			2011	16.0 (-)	17.5 (8)	18.7 (-)	14.4 (-)	14.2 (-)	2011	13 (-)	12 (9)	13 (-)	17 (-)	13 (-)	
2012	19.2 (-)	16.7 (-)	15.1 (4)	17.3 (-)	12.8 (-)	2012	10 (-)	14 (-)	9 (9)	15 (-)	5 (-)				
2013	17.1 (-)	18.5 (-)	18.8 (-)	14.3 (-)	14.1 (17.0)	2013	8 (-)	10 (-)	10 (-)	10 (-)	7 (36)				
Averaged period POD_y (mmol m⁻²) Biomass reduction			Mean diurnal NO variation: POD_y exceedance (non-exceedance) (ppb)					Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days							
			5	6	7	8	9		Northerly	Easterly	Southerly	Westerly			
			2007	3.2 (-)	5.6 (-)	3.1 (-)	3.3 (-)	2.0 (-)	2007	28% (43%)	23% (3%)	7% (13%)	42% (42%)		
			2008	3.1 (-)	1.3 (-)	2.7 (-)	1.5 (-)	2.6 (-)	2008	18% (38%)	27% (2%)	12% (0%)	42% (60%)		
			2009	0.7 (-)	2.0 (-)	0.6 (-)	1.5 (-)	1.6 (7.2)	2009	20% (19%)	20% (10%)	23% (40%)	38% (31%)		
			2010	2.6 (-)	2.1 (-)	1.4 (-)	2.4 (-)	3.0 (-)	2010	21% (0%)	14% (31%)	41% (67%)	23% (2%)		
			2011	1.5 (-)	1.6 (8.8)	2.2 (-)	2.6 (-)	1.6 (-)	2011	30% (19%)	11% (0%)	35% (46%)	24% (35%)		
2012	2.6 (-)	1.2 (-)	1.9 (0)	1.1 (-)	1.4 (-)	2012	28% (58%)	17% (7%)	27% (0%)	27% (36%)					
2013	1.4 (-)	1.8 (-)	1.5 (-)	2.8 (-)	2.6 (27.2)	2013	21% (32%)	13% (13%)	31% (31%)	34% (25%)					
Spatial domain Auchencorth EMEP level 2 Supersite, lat: 55.792160 long: -3.242900			Mean diurnal NO₂ variation: POD_y exceedance (non-exceedance) (ppb)												
Representivity Central/northern UK (Malley et al., 2014a) AURN classification: Rural Background			5	6	7	8	9								
Temporal Domain O ₃ statistics: 2007-2013 NO _x statistics: 2007-2013 (data from proxy site Bush)			2007	8.3 (-)	12.5 (-)	5.3 (-)	6.1 (-)	5.7 (-)							
			2008	10.8 (-)	5.5 (-)	6.5 (-)	5.8 (-)	7.7 (-)							
			2009	4.2 (-)	6.7 (-)	3.7 (-)	3.3 (-)	5.3 (8.5)							
			2010	7.8 (-)	6.6 (-)	3.8 (-)	6.3 (-)	7.6 (-)							
			2011	3.8 (-)	4.4 (22.9)	5.9 (-)	5.7 (-)	3.8 (-)							
			2012	7.9 (-)	5.1 (-)	5.0 (0.5)	4.4 (-)	4.1 (-)							
			2013	6.5 (-)	5.5 (-)	5.7 (-)	5.9 (-)	6.6 (17.6)							

Table S11: Chemical climate datasheet summarising the impact of O₃ on Scots pine at Harwell.

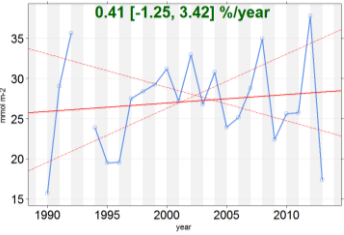

Impact			State							Drivers																																																																																																																											
Ozone impact on PINE Critical levels for coniferous trees based on whole tree biomass reductions. Scots pine representative tree for 'atlantic central Europe' (LRTAP Convention, 2010). Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (year round when daily mean temperature >0 °C). Annual POD_y 1990-2013 Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05) 			Annual and monthly no. of POD_y exceedance days							Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)																																																																																																																											
			<table border="1"> <thead> <tr> <th>Annual</th> <th>3</th> <th>4</th> <th>5</th> <th>6</th> <th>7</th> <th>8</th> <th>9</th> </tr> </thead> <tbody> <tr> <td>90-93</td> <td>291</td> <td>31</td> <td>28</td> <td>29</td> <td>30</td> <td>28</td> <td>27</td> <td>25</td> </tr> <tr> <td>94-97</td> <td>294</td> <td>28</td> <td>30</td> <td>27</td> <td>28</td> <td>29</td> <td>24</td> <td>20</td> </tr> <tr> <td>98-01</td> <td>325</td> <td>29</td> <td>22</td> <td>30</td> <td>30</td> <td>30</td> <td>30</td> <td>30</td> </tr> <tr> <td>02-05</td> <td>324</td> <td>30</td> <td>30</td> <td>31</td> <td>30</td> <td>31</td> <td>31</td> <td>29</td> </tr> <tr> <td>06-09</td> <td>316</td> <td>23</td> <td>23</td> <td>29</td> <td>29</td> <td>30</td> <td>30</td> <td>30</td> </tr> <tr> <td>10-13</td> <td>316</td> <td>28</td> <td>24</td> <td>31</td> <td>29</td> <td>28</td> <td>30</td> <td>29</td> </tr> </tbody> </table>							Annual	3	4	5	6	7	8	9	90-93	291	31	28	29	30	28	27	25	94-97	294	28	30	27	28	29	24	20	98-01	325	29	22	30	30	30	30	30	02-05	324	30	30	31	30	31	31	29	06-09	316	23	23	29	29	30	30	30	10-13	316	28	24	31	29	28	30	29	<table border="1"> <thead> <tr> <th>3</th> <th>4</th> <th>5</th> <th>6</th> <th>7</th> <th>8</th> <th>9</th> </tr> </thead> <tbody> <tr> <td>90-93</td> <td>7.9 (5.7)</td> <td>8.2 (5.8)</td> <td>12.0 (12.2)</td> <td>14.0 (14.6)</td> <td>17.2 (17.0)</td> <td>17.6 (17.4)</td> <td>13.9 (12.8)</td> </tr> <tr> <td>94-97</td> <td>6.3 (4.3)</td> <td>8.2 (4.7)</td> <td>10.7 (5.4)</td> <td>14.5 (-)</td> <td>17.4 (17.3)</td> <td>18.0 (17.9)</td> <td>12.1 (14.3)</td> </tr> <tr> <td>98-01</td> <td>7.0 (5.7)</td> <td>8.5 (-0.8)</td> <td>12.4 (-)</td> <td>14.6 (-)</td> <td>16.7 (-)</td> <td>16.5 (14.3)</td> <td>14.6 (11.8)</td> </tr> <tr> <td>02-05</td> <td>6.9 (6.2)</td> <td>9.1 (-)</td> <td>11.8 (-)</td> <td>15.6 (-)</td> <td>16.7 (14.1)</td> <td>17.4 (21.0)</td> <td>14.5 (14.3)</td> </tr> <tr> <td>06-09</td> <td>6.1 (4.1)</td> <td>9.6 (8.1)</td> <td>12.7 (-)</td> <td>15.6 (-)</td> <td>17.2 (16.4)</td> <td>16.2 (18.7)</td> <td>14.4 (14.7)</td> </tr> <tr> <td>10-13</td> <td>5.6 (3.3)</td> <td>9.1 (8.3)</td> <td>11.5 (-)</td> <td>14.6 (-)</td> <td>16.9 (18.8)</td> <td>16.3 (20.3)</td> <td>13.9 (13.6)</td> </tr> </tbody> </table>							3	4	5	6	7	8	9	90-93	7.9 (5.7)	8.2 (5.8)	12.0 (12.2)	14.0 (14.6)	17.2 (17.0)	17.6 (17.4)	13.9 (12.8)	94-97	6.3 (4.3)	8.2 (4.7)	10.7 (5.4)	14.5 (-)	17.4 (17.3)	18.0 (17.9)	12.1 (14.3)	98-01	7.0 (5.7)	8.5 (-0.8)	12.4 (-)	14.6 (-)	16.7 (-)	16.5 (14.3)	14.6 (11.8)	02-05	6.9 (6.2)	9.1 (-)	11.8 (-)	15.6 (-)	16.7 (14.1)	17.4 (21.0)	14.5 (14.3)	06-09	6.1 (4.1)	9.6 (8.1)	12.7 (-)	15.6 (-)	17.2 (16.4)	16.2 (18.7)	14.4 (14.7)	10-13	5.6 (3.3)	9.1 (8.3)	11.5 (-)	14.6 (-)	16.9 (18.8)	16.3 (20.3)	13.9 (13.6)
			Annual	3	4	5	6	7	8	9																																																																																																																											
			90-93	291	31	28	29	30	28	27	25																																																																																																																										
			94-97	294	28	30	27	28	29	24	20																																																																																																																										
			98-01	325	29	22	30	30	30	30	30																																																																																																																										
			02-05	324	30	30	31	30	31	31	29																																																																																																																										
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06-09	6.1 (4.1)	9.6 (8.1)	12.7 (-)	15.6 (-)	17.2 (16.4)	16.2 (18.7)	14.4 (14.7)																																																																																																																														
10-13	5.6 (3.3)	9.1 (8.3)	11.5 (-)	14.6 (-)	16.9 (18.8)	16.3 (20.3)	13.9 (13.6)																																																																																																																														
Monthly % contribution to POD_y							Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)																																																																																																																														
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98-01	42 (68)	40 (21)	41 (-)	42 (-)	43 (-)	40 (28)	43 (21)																																																																																																																														
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<table border="1"> <thead> <tr> <th>3</th> <th>4</th> <th>5</th> <th>6</th> <th>7</th> <th>8</th> <th>9</th> </tr> </thead> <tbody> <tr> <td>90-93</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> </tr> <tr> <td>94-97</td> <td>17.0 (18.0)</td> <td>15.7 (28.7)</td> <td>11.6 (-)</td> <td>11.2 (-)</td> <td>7.9 (-)</td> <td>-</td> <td>10.6 (7.4)</td> </tr> <tr> <td>98-01</td> <td>13.8 (22.3)</td> <td>10.4 (2.1)</td> <td>11.9 (-)</td> <td>10.2 (-)</td> <td>8.8 (-)</td> <td>11.1 (11.7)</td> <td>10.5 (-)</td> </tr> <tr> <td>02-05</td> <td>15.0 (17.2)</td> <td>12.0 (-)</td> <td>8.2 (-)</td> <td>7.3 (-)</td> <td>7.0 (9.0)</td> <td>9.4 (6.6)</td> <td>11.8 (8.6)</td> </tr> <tr> <td>06-09</td> <td>7.6 (5.9)</td> <td>9.2 (0)</td> <td>9.0 (-)</td> <td>8.1 (-)</td> <td>6.1 (2.1)</td> <td>6.2 (5.3)</td> <td>8.9 (10.6)</td> </tr> <tr> <td>10-13</td> <td>12.7 (10.7)</td> <td>6.9 (-)</td> <td>6.3 (-)</td> <td>6.3 (-)</td> <td>5.4 (4.4)</td> <td>5.6 (3.9)</td> <td>7.8 (2.1)</td> </tr> </tbody> </table>							3	4	5	6	7	8	9	90-93	-	-	-	-	-	-	94-97	17.0 (18.0)	15.7 (28.7)	11.6 (-)	11.2 (-)	7.9 (-)	-	10.6 (7.4)	98-01	13.8 (22.3)	10.4 (2.1)	11.9 (-)	10.2 (-)	8.8 (-)	11.1 (11.7)	10.5 (-)	02-05	15.0 (17.2)	12.0 (-)	8.2 (-)	7.3 (-)	7.0 (9.0)	9.4 (6.6)	11.8 (8.6)	06-09	7.6 (5.9)	9.2 (0)	9.0 (-)	8.1 (-)	6.1 (2.1)	6.2 (5.3)	8.9 (10.6)	10-13	12.7 (10.7)	6.9 (-)	6.3 (-)	6.3 (-)	5.4 (4.4)	5.6 (3.9)	7.8 (2.1)																																																																									
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Average annual POD_y and % yield reduction for quartile groups																																																																																																																																					
Averaged period	POD_y (mmol m⁻²)	Biomass reduction																																																																																																																																			
1990-1993	27.1 ± 8.3	Response function not available for Scots pine.																																																																																																																																			
1994-1997	22.6 ± 3.8																																																																																																																																				
1998-2001	29.0 ± 4.9																																																																																																																																				
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2010-2013	26.6 ± 8.4																																																																																																																																				
Spatial domain			Representivity																																																																																																																																		
Harwell EMEP level 2 Supersite, lat: 51.571078 long: -1.325283			S and SE UK (Malley et al., 2014a) AURN classification: Rural Background																																																																																																																																		
Temporal Domain																																																																																																																																					
O ₃ data: 1990-2013 NO _x data: 1996-2013																																																																																																																																					

Table S12: Chemical climate datasheet summarising the impact of O₃ on Scots pine at Auchencorth.

Impact			State								Drivers																		
Ozone impact on PINE Critical levels for coniferous trees based on whole tree biomass reductions. Scots pine representative coniferous tree for 'atlantic central Europe' (LRTAP Convention, 2010). Metric Phytotoxic O ₃ Dose above a flux threshold of Y nmol m ⁻² s ⁻¹ (POD _y) calculates accumulated stomatal flux of O ₃ into the plant across growing season (year round when daily mean temperature >0 °C).			Annual and monthly no. of POD_y exceedance days								Meteorology: Av. Temp on exceedance (non-exceedance) days (°C)																		
			2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7	8	9	10	2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7
Annual POD_y 2007-2013. Theil Sen trend estimate is not statistically significant (<i>p</i> = 0.05)			Monthly % contribution to POD_y								Av. Global radiation on exceedance (non-exceedance) days (W m⁻²)																		
			2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7	8	9	10	2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7
			Mean diurnal O₃ variation: POD_y exceedance (non-exceedance) (ppb)								Emissions: Average hourly NO_x emissions along 96 hour back trajectory path arriving on POD_y exceedance (non-exceedance) days (Mg)																		
Average annual POD_y and % yield reduction for quartile groups			Year								Year																		
			2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7	8	9	10	2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7
Spatial domain Auchencorth EMEP level 2 Supersite, lat: 55.792160 long: -3.242900			Representivity Central/northern UK (Malley et al., 2014a) AURN classification: Rural Background								Mean diurnal NO variation: POD_y exceedance (non-exceedance) (ppb)																		
Temporal Domain O ₃ statistics: 2007-2013 NO _x statistics: 2007-2013 (data from proxy site Bush)			Year								Year																		
			2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7	8	9	10	2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7
			Mean diurnal NO₂ variation: POD_y exceedance (non-exceedance) (ppb)								Air Mass origin: Percentage of trajectories from 4 geographical groupings on exceedance (non-exceedance) days																		
Year			Year								Year																		
			2007	2008	2009	2010	2011	2012	2013	3	4	5	6	7	8	9	10	2007	2008	2009	2010	2011	2012	2013	Northerly	Easterly	Southerly	Westerly	

