Transboundary particulate matter pollution on Gibraltar

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AEA group
329 Harwell
Didcot
Oxfordshire
OX11 0QJ

t: 0870 190 6401
f: 0870 190 6318

Author	Name	John Abbott
Approved by	Name	
	Signature	
	Date	

Executive summary

Sources of emissions of oxides of nitrogen, oxides of sulphur and particulate matter throughout the world contribute to a greater or lesser extent to the concentrations of these pollutants in Gibraltar. In this study, the contributions from sources outside Gibraltar are assessed.

The contribution from emissions to pollutant concentrations throughout Europe has been modelled under the European Monitoring and Evaluation Programme (EMEP). EMEP is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution for international co-operation to solve transboundary air pollution problems. The EMEP model takes account of emissions from the whole of Europe, parts of North Africa and the Middle East, and the North East Atlantic including the east coast of Canada.

The EMEP model predicts that transboundary pollution contributed 2.8 $\mu g\ m^{-3}$ to annual mean primary PM_{10} concentrations and 5.4 $\mu g\ m^{-3}$ to annual mean secondary inorganic PM_{10} concentrations in Gibraltar in 2006. These values are small compared with the measured concentration at the Rosia Road monitoring site of 39.8 $\mu g\ m^{-3}$ in 2006. It is concluded that the transboundary sources modelled by the EMEP model only contribute a relatively small part of the total concentration at the 50 km spatial resolution of the model.

The EMEP model does not provide estimates of the contribution from secondary organic aerosol and resuspended and wind-eroded mineral dust. The contribution from resuspended and wind-eroded mineral dust will be determined experimentally by analysis of particulate matter collected by samplers at the monitoring stations in Gibraltar and is the subject of a separate report. There are no measurements of secondary organic aerosol concentrations in Gibraltar and few in Spain. Measurements in Madrid indicated that daily average secondary organic aerosol concentrations were typically approximately 1 $\mu g\ m^{-3}$ during high concentration episodes. Concentrations in Gibraltar are likely to be similar and so it is concluded that secondary organic aerosols do not make a substantial contribution to PM_{10} concentrations in Gibraltar.

The EMEP model only provides predictions of pollutant concentrations at a spatial resolution of 50 km. The concentration in each 50 km square is approximately the average concentration and the concentrations will be higher near local sources within the 50 km square. The contributions from sources near Gibraltar in the Spanish province of Cadiz and in northern Morocco were assessed using the ADMS4.1 dispersion model. The local sources taken into account included CEPSA refinery and the UPT power station. The total contribution from nearby sources in Spain and Morocco was estimated to be 0.6 $\mu g\ m^{-3}$ as an annual mean at Rosia Road and 0.4 $\mu g\ m^{-3}$ as an annual mean at Bleak House. This is small compared with the measured annual mean PM_{10} concentration at the Rosia Road roadside site in Gibraltar of 39.8 $\mu g\ m^{-3}$ in 2006. It was concluded that nearby sources of emission in Spain and Morocco do not make a substantial contribution to PM_{10} concentrations in Gibraltar.

Table of contents

1 Introduction

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The EMEP model predicts concentrations on a regular grid at 50 km resolution. More detailed modelling of the emissions from the Spanish province of Cadiz and the Moroccan provinces of Teteouan and Tanger using the ADMS dispersion model is described in Section 3.

Particulate matter, PM_{10}, measured at ambient monitoring sites is made up of several components:

- primary particulate matter emitted directly from industrial, domestic, commercial and transport activities mostly as the result of combustion processes;
- secondary particulate matter, inorganic and organic, formed in the atmosphere as the result of reactions of gaseous emissions with constituents of the atmosphere;
- naturally occurring dusts, including suspended soil matter, sea-salt, pollen.

The contribution from naturally-occurring dusts to PM_{10} concentrations is considered in a separate report. The contribution from shipping in the Straits of Gibraltar is also considered in a separate report.

2 EMEP model results

2.1 Introduction

The results of the EMEP model are summarised in this section. The model results were downloaded from the EMEP website http://webdab.emep.int/Unified_Model_Results/AN/

The EMEP model provides predictions of the components of particulate matter shown in Table 1. The model does not provide predictions of the contributions from secondary organic aerosol and resuspended and wind-eroded mineral dust. The model also provides predictions of nitrogen dioxide concentrations. EMEP also run extended versions of the model, with a wider range of particulate matter components. The results of the extended versions of the model are included in annual status reports. For example, the 2007 annual status report[1] includes an evaluation of model predictions of secondary organic aerosol but these are not yet considered to be sufficiently reliable for inclusion within the standard model.

Table 1: Components of particulate matter included in the EMEP model and reported on the website

Component of particulate matter	Description
Particulate sulphate	Formed from sulphur oxides emissions as the result of reactions with hydroxyl radicals in the gas phase and hydrogen peroxide, ozone and oxygen in cloud aerosol.
Fine particulate nitrate	Formed from oxides of nitrogen emissions as the result of reactions with ozone and water in the atmosphere. Particles<2.5 μm.
Coarse particulate nitrate	Formed from oxides of nitrogen emissions as the result of reactions with ozone and water in the atmosphere and adsorbed onto other particulate matter.
Fine particulate ammonium	Particulate matter formed as the results of reactions of ammonia emissions with acidic species in the atmosphere. Particles<2.5 μm.
Primary $PM_{2.5}$	Particulate matter less than 2.5 μm emitted directly into the atmosphere
Primary coarse	Particulate matter, 2.5-10 μm, emitted directly into the atmosphere
Primary PM_{10}	Primary $PM_{2.5}$+ Primary coarse
Sea salt	Sea salt emissions resulting from bubble bursting during whitecap formation
Secondary inorganic aerosol	The sum of particulate sulphate, fine and coarse nitrate and ammonium
$PM_{2.5}$	Fine particulate matter with diameter up to 2.5 μm. Calculated as the sum of particulate sulphate, fine particulate nitrate, ammonium and primary $PM_{2.5}$.
PM_{10}	Particulate matter matter with diameter up to 10 μm. Calculated as the sum of $PM_{2.5}$, coarse particulate nitrate, primary coarse (and seasalt in the latest versions of the model output).

2.2 Results

Table 2 lists the model predictions of nitrogen dioxide and particulate matter concentrations for the years 2001 to 2006 for the 50 km square area (EMEP coordinates 62, 2) that includes Gibraltar.

[1] Transboundary particulate matter in Europe Status report 2007 http://tarantula.nilu.no/projects/ccc/reports/emep4-2007.pdf

Table 2: Predicted concentrations for the 50 km square that includes Gibraltar

Component	Units	2006	2005	2004	2003	2002	2001
Nitrogen dioxide	μg N m^{-3}	6.634	6.004	6.496	5.859	6.079	5.761
Particulate sulphate	μg S m^{-3}	1.149	1.140	1.198	1.147	1.261	1.225
Fine particulate nitrate	μg N m^{-3}	0.035	0.046	0.051	0.061	0.053	0.032
Coarse particulate nitrate	μg N m^{-3}	0.131	0.147	0.164	0.141	0.145	0.150
Fine particulate ammonium	μg N m^{-3}	0.943	0.942	0.984	0.943	0.993	0.969
Seasalt	μg m^{-3}	1.572	-	-	-	-	-
Primary PM_{10}	μg m^{-3}	2.819	2.713	3.096	2.747	2.831	2.746
Primary $PM_{2.5}$	μg m^{-3}	2.706	2.601	2.904	2.573	2.644	2.567
Primary coarse	μg m^{-3}	0.112	0.117	0.193	0.173	0.186	0.179
PM_{10}	μg m^{-3}	9.875	8.202	8.906	8.294	8.771	8.472
$PM_{2.5}$	μg m^{-3}	7.875	7.439	7.989	7.497	7.942	7.629
Coarse particulate matter	μg m^{-3}	1.910	0.762	0.917	0.796	0.828	0.843

The predicted concentrations in Gibraltar change relatively little from year to year over the period 2001-2006. Some of the variation between years may be attributed to the use of different versions of the model: for example, model results for 2006 include seasalt whereas this was not included in earlier years.

Table 3 shows the modelled reduction in the concentrations in particulate matter components for 2006 in the 50 km square area (EMEP coordinates 62, 2) that includes Gibraltar for a 15% reduction in emissions from emission sources in Spain, the whole of the European Union and from North Africa.

Table 3: Predicted reduction in concentrations for a 15% reduction in emissions

Component	Units	Contribution from Spain	Contribution from European Union	Contribution from North Africa
Primary $PM_{2.5}$	μg m^{-3}	0.078		
Primary coarse	μg m^{-3}	0.031		
$PM_{2.5}$	μg m^{-3}	0.297		
Secondary inorganic aerosol	μg m^{-3}	0.243	0.358	0.050

2.3 EMEP Model evaluation

The EMEP model predictions been evaluated extensively by comparison against measured concentrations at monitoring stations throughout the model domain. Annual status reports provide summaries of comparisons against the most recent monitoring data.[2]

Pollutant concentrations are measured at various locations throughout southern Spain. Measurements of concentrations of nitrogen dioxide, secondary sulphate PM_{10}, secondary nitrate PM_{10}, PM_{10} and $PM_{2.5}$ are measured at monitoring sites at Viznar, Bacarrola, Zarra and Risco Llamo and are reported

[2] Transboundary particulate matter in Europe Status report 2008. http://tarantula.nilu.no/projects/ccc/reports/emep4-2008.pdf
Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe in 2006.
http://www.emep.int/publ/reports/2008/status_report_1_2008.pdf

to EMEP. The modelled and measured annual mean concentrations at these sites are listed in Table 4.

Table 4: Measured and modelled concentrations at EMEP sites in Spain

Site	Component	Units	Concentration					
			Measured			Modelled		
			2006	2005	2004	2006	2005	2004
ES07 Viznar 37°14'0"N 3°32'0"W	NO_2	μg N m^{-3}	2.23	2.15	2.45	0.77	0.66	0.72
	SO_4, PM_{10}	μg S m^{-3}	0.69	0.74	0.81	0.53	0.51	0.50
	NO_3 PM_{10}	μg N m^{-3}	0.45	0.47	0.49	0.18	0.21	0.22
	PM_{10}	μg m^{-3}	20.18	21.75	24.44	-	3.97	4.02
	$PM_{2.5}$	μg m^{-3}	10.12	10.88	11.09	3.45	3.43	3.41
ES11 Barcarrola 38°28'33"N 6°55'22"W	NO_2	μg N m^{-3}	1.06	1.31	1.34	0.58	0.50	0.55
	SO_4, PM_{10}	μg S m^{-3}	0.69	0.79	0.83	0.57	0.59	0.52
	NO_3 PM_{10}	μg N m^{-3}	0.29	0.34	0.28	0.21	0.24	0.23
	PM_{10}	μg m^{-3}	15.53	18.97	18.6	4.95	4.73	4.40
	$PM_{2.5}$	μg m^{-3}	8.55	10.19	10.69	4.23	4.25	3.91
ES12 Zarra 39°00'5'10"N 01°06'07"W	NO_2	μg N m^{-3}	1.36	1.08	1.15	1.68	1.49	1.64
	SO_4, PM_{10}	μg S m^{-3}	0.80	0.86	1.00	0.70	0.63	0.62
	NO_3 PM_{10}	μg N m^{-3}	0.42	0.41	0.45	0.31	0.37	0.37
	PM_{10}	μg m^{-3}	14.07	15.32	17.23	-	5.97	5.91
	$PM_{2.5}$	μg m^{-3}	8.37	7.79	8.32	5.39	5.35	5.27
ES15 Risco Llamo 39°00'31'0"N 04°21'0"W	NO_2	μg N m^{-3}	1.22	1.19	0.92	1.09	0.97	1.03
	SO_4, PM_{10}	μg S m^{-3}	0.51	0.62	0.63	0.50	0.48	0.45
	NO_3 PM_{10}	μg N m^{-3}	0.31	0.35	0.35	0.28	0.33	0.34
	PM_{10}	μg m^{-3}	13.46	15.14	15.91	4.89	4.81	4.89
	$PM_{2.5}$	μg m^{-3}	8.71	7.98	8.25	4.27	4.33	4.29

The nitrogen dioxide concentrations at these sites are relatively low compared to those measured in Gibraltar. At two of the site the model underestimated the measured concentrations and at two of the sites it overestimated the measured concentrations. On average, it underestimated the concentrations at these sites by approximately 33%. The measured concentration at the background site in Gibraltar at Bleak House was 7.33 μg N m^{-3} (=24.1 μg m^{-3}) in 2006 and 7.27 μg N m^{-3} (=23.9μg m^{-3}) in 2005: these values are approximately 10% greater than the modelled concentrations of 6.63 μg N m^{-3} (=21.8 μg m^{-3}) in 2006 and 6.00 μg N m^{-3} (=19.7μg m^{-3}) in 2005.

The model underestimated the sulphate PM_{10} concentrations at all the EMEP sites in southern Spain. On average, it underestimated the concentrations at these sites by approximately 26%.

The model underestimated the nitrate PM_{10} concentrations at all the EMEP sites in southern Spain. On average, it underestimated the concentrations at these sites by approximately 29%.

The model substantially underestimated the PM_{10} and $PM_{2.5}$ concentrations at the monitoring stations in Southern Spain. The measured annual mean PM_{10} concentration at the Rosia Road roadside site in Gibraltar was 39.8 μg m^{-3} in 2006 (2007: 44.8 μg m^{-3}. 2008: 39.4 μg m^{-3}): the annual mean $PM_{2.5}$ concentration was 18.9 μg m^{-3} (2007: 18.5 μg m^{-3}. 2008: 15.8 μg m^{-3}). The model thus also underestimated the concentration at Rosia Road, although the measurements at this site were to some extent affected by local road traffic emissions. Measurements of PM_{10} concentrations have only been made at the Bleak House background monitoring site in Gibraltar since June 2008:, the average concentration in the 6 months to the end of 2008 was 33.7 μg m^{-3} compared with the modelled concentration for 2006 of 9.9 μg m^{-3}. However, the model does not provide predictions of the contributions from secondary organic matter and resuspended and wind-eroded mineral dust. The

contribution from resuspended and wind-eroded mineral dust to particulate concentrations in Gibraltar will be considered in a separate report.

2.4 Discussion

The evaluation of the model indicates that the model provides reasonable estimates of the particulate sulphate and particulate nitrate concentrations at monitoring stations throughout southern Spain typically underestimating by less than 30%. It does not provide useful estimates of total $PM_{2.5}$ and PM_{10} concentrations because contributions from secondary organic aerosol and resuspended and wind-eroded mineral dust are not included in the model. Typically, the components included in the model account for approximately 30% of the PM_{10} concentrations in Gibraltar and in southern Spain.

There are few measurements of secondary organic aerosol concentrations in Spain. Plaza et al[3] measured concentrations of secondary organic aerosols in Madrid during summer and winter episodes. Peak hourly secondary organic aerosol concentrations during the episodes were approximately 4 μg C m^{-3} (~10 μg m^{-3} organic aerosol) with peak daily average concentrations approximately a third of that. It is possible that concentrations in Gibraltar might approach these concentrations.

Table 5 shows the contribution to the total modelled PM_{10} concentrations for the 50 km square that includes Gibraltar. Fig.1 shows a pie chart of the modelled contributions.

Table 5: Modelled contributions to PM_{10} concentrations in Gibraltar, 2006

Modelled component	Units	Concentration in reported units	Molecular weight factor*	Concentration, μg m^{-3}
fine NO3	μg N m^{-3}	0.035	62/14	0.155
SO4	μg S m^{-3}	1.149	96/32	3.447
fine NH4	μg N m^{-3}	0.943	18/14	1.212
Primary PM2.5	μg m^{-3}	2.706	1	2.706
Coarse NO3	μg N m^{-3}	0.131	62/14	0.580
Primary coarse	μg m^{-3}	0.112	1	0.112
Seasalt	μg m^{-3}	1.572	1	1.572
Total				9.785
*Factor to convert from μg N m^{-3} or μg S m^{-3} to μg m^{-3} based on the molecular weights of the modelled species compared to that of nitrogen or sulphur				

[3] J. Plaza, F.J. Gomez-Moreno, L. Nunez, M. Pujadas, B. Artınano. Estimation of secondary organic aerosol formation from semicontinuous OC–EC measurements in a Madrid suburban area. Atmospheric Environment 40 (2006) 1134–1147

Fig. 1: Modelled contributions to PM_{10} concentrations in Gibraltar, 2006

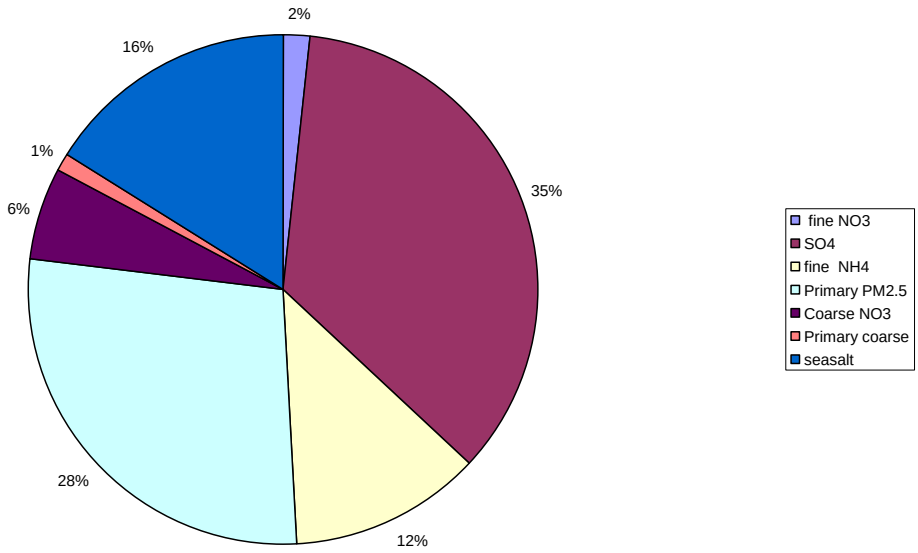


Fig. 1 shows that the largest modelled contribution is from particulate sulphate, followed by primary $PM_{2.5}$ and seasalt.

The total secondary inorganic aerosol (sulphate plus nitrate +ammonium) in Table 5 is 5.39 μg m^{-3}, approximately 55% of the modelled PM_{10} concentrations. Table 3 indicates that a 15% reduction in emissions from Spain would reduce this by 0.243 μg m^{-3}. Assuming that the relationship between emissions in Spain and concentrations in the area of Gibraltar is approximately linear, then the contribution from emission sources estimated to be 1.62 μg m^{-3}, which is approximately 30% of the total secondary inorganic aerosol concentration.

The EMEP model provides predictions at a resolution of 50 km x 50 km. The concentration in each 50 km square is approximately the average concentration and the concentrations will be higher near local sources within the 50 km square. The contribution from sources near Gibraltar in the Spanish province of Cadiz and in northern Morocco are assessed in Section 3. The contributions from sources within Gibraltar and from shipping are assessed in separate reports.

3 Local emission sources in Spain and Morocco

3.1 Introduction

The impact of local emission sources in Spain and Morocco at distances up to approximately 50 km is considered in this section. The ADMS4 dispersion model was used to predict the concentration of pollutant concentrations in Gibraltar from reported emissions.

3.2 Emissions

3.2.1 Nearby major industrial sources in Spain

Large local industrial emission sources were identified from the European Environment Agency's European Pollutant Emission Register.[4] Further information was obtained from Registro Estatal de Emisiones y Fuentes Contaminantes[5]. Table 6 lists the reported emissions fro the years 2004-2007. Facilities are not required to report emission less than threshold limits of 100 tonnes per annum of oxides of nitrogen, 150 tonnes per annum of oxides of sulphur and 50 tonnes per annum of PM_{10}.

Nickel compounds make up part of the particulate matter emitted from the large industrial sources. Table 6 shows the total emissions from the main sources taken from the Registro Estatal de Emisiones y Fuentes Contaminantes.

The emissions from these sources were treated as individual point sources within the dispersion modelling.

[4] http://eper.ec.europa.eu/eper/
[5] http://www.prtr-es.es/

Table 6: Nearby large point sources in Spain

FacilityName	Longitude	Latitude	NOx, tonnes				SOx, tonnes				PM10, tonnes				Ni, tonnes	Industry
			2004	2005	2006	2007	2004	2005	2006	2007	2004	2005	2006	2007	2007	
Refinería Gibraltar	-5.39735	36.1839	2190	1910	1850	1520	18700	13400	8440	10900	387	341	225	307	0.256	Manufacture of refined petroleum products
Petresa	-5.39515	36.18964	538	428	328	278	1880	1300	597	334	80.2	-	-	-	0.102	Manufacture of other organic basic chemicals
Acerinox, S.A.	-5.42124	36.18393	114	112	113	164	-	-	-	-	62.6	50.8	-	-	0.056	Manufacture of basic iron and steel and of ferro-alloys (ECSC)*
Intercontinental Química, S.A. (Interquisa)	-5.40906	36.20465	105	128	-	183	-	-	-	-	-	-	-	65.6		Manufacture of other organic basic chemicals
Lubrisur	-5.39457	36.18835	263	225	295	213	1720	1110	924	852	-	-	-	-		Manufacture of refined petroleum products
C.T. Bahía Algeciras	-5.38798	36.18403	627	1010	255	-	1680	2870	714	-	50.6	76.0	-	-		Production and distribution of electricity
Upt Los Barrios	-5.41841	36.1837	8450	8020	7010	7890	14100	17300	14200	16400	1020	1020	824	731	0.080	Production and distribution of electricity
Cerámica La Esperanza, S.A.	-5.3854	36.21002	-	-	-	-	-	-	-	-	82.9	-	-	56.5		Manufacture of bricks, tiles and& construction products, in baked clay
Cogeneración De Refinería Gibraltar	-5.3854	36.21002	389	381	437	553	228	-	-	-	-	-	-	-		Production and distribution of electricity
Cogeneración De Interquisa	-5.40745	36.20531	758	288	495	833	-	-	-	-	-	-	-	-		Production and distribution of electricity
Juanjo, S.L.	-5.83056	36.75112	-	-	-	-	-	-	10.76	-	118	-	66.1	209		Manufacture of bricks, tiles and& construction products, in baked clay
Bovedillas Cerámicas Andaluzas, S.A.	-5.82895	36.75296	-	-	-	-	-	-	-	-	75.5	-	-	-		Manufacture of bricks, tiles and& construction products, in baked clay
San Roque Grupo 1	-5.41336	36.19251	360	254	337	276	-	-	-	-	-	-	-	-		Production and distribution of electricity
San Roque Grupo 2	-5.41286	36.19978	389	507	316	290	-	-	-	-	-	-	-	-		Production and distribution of electricity
Nueva Generadora Del Sur, S.A. - Central Termica De Ciclo Combinado "Campo De Gibraltar"	-5.39102	36.18537	148	386	297	537	-	-	-	-	-	81.6	-	-		Production and distribution of electricity
Central De Ciclo Combinado Arcos de la Frontera	-5.181516	36.67521	-	797	611	367	-	-	-	-	-	-	-	-		Production and distribution of electricity

3.2.2 Other sources in Spain

The Junta de Andalucia has prepared an emission inventory[6] for air pollutants for the year 2005. The emissions are attributed to each municipality by emission sector (e.g agriculture, road transport, electricity generation). Table 7 lists the total annual emissions of oxides of nitrogen, sulphur dioxide and particulate matter, PM_{10} and $PM_{2.5}$ for each municipality.

[6] http://www.juntadeandalucia.es/medioambiente/site/web/menuitem.2d0dd65d4aa72c321914e90a821001ca/?ima_anyo=2007&ima_tema=080101&ima_subtema=1&ima_tabla=080107&vgnextoid=eb23c70df517a010VgnVCM1000000624e50aRCRD

Table 7: Annual emissions from municipalities in Cadiz

Municipality	NO_x (t)	SO_2 (t)	PM_{10} (t)	$PM_{2,5}$ (t)
Alcala De Los Gazules	174.96	3.17	24.45	21.98
Alcala Del Valle	55.22	1.55	17.94	15.46
Algar	18.94	0.43	6.05	5.29
Algeciras	5,071.35	3,237.14	519.26	507.69
Algodonales	102.76	2.11	21.56	19.62
Arcos De La Frontera	1,352.28	278.57	118.05	105.47
Barbate De Franco	148.92	18.87	32.60	29.41
Barrios (Los)	8,529.90	17,339.44	1,130.65	385.39
Benalup	61.28	2.79	11.11	10.03
Benaocaz	22.34	0.32	5.39	4.86
Bornos	77.58	2.82	17.06	15.28
Bosque (El)	29.91	0.80	8.49	7.28
Cadiz	1,852.51	2,306.91	208.59	197.09
Castellar De La Frontera	79.31	1.86	14.19	13.19
Chiclana De La Frontera	457.48	15.19	83.74	73.57
Chipiona	146.95	6.21	38.67	35.70
Conil De La Frontera	183.00	27.82	51.70	43.25
Espera	80.33	1.62	16.36	14.64
Gastor (El)	32.06	0.68	7.89	7.19
Grazalema	67.05	1.43	13.64	12.56
Jerez De La Frontera	4,579.75	308.02	484.94	380.84
Jimena De La Frontera	188.84	5.17	33.66	30.67
Linea De La Concepcion (La)	242.93	26.87	51.88	45.02
Medina-Sidonia	277.98	7.97	47.08	41.45
Olvera	143.33	35.47	58.99	44.03
Paterna De Rivera	35.71	12.20	11.39	10.70
Prado Del Rey	51.02	1.55	13.04	11.14
Puerto De Santa Maria (El)	1,253.99	39.37	120.22	109.85
Puerto Real	1,221.50	92.98	93.00	86.48
Puerto Serrano	53.81	1.95	18.97	16.34
Rota	302.72	9.08	56.63	50.40
San Fernando	295.90	17.20	67.79	59.09
San Jose Del Valle	115.99	3.34	24.81	18.33
San Roque	6,749.18	19,191.39	772.25	442.17
Sanlucar De Barrameda	404.07	16.14	95.48	83.58
Setenil	64.94	1.57	30.69	20.70
Tarifa	243.47	23.03	36.23	31.41
Torre-Alhaquime	17.35	0.44	5.47	4.21
Trebujena	104.66	2.45	28.31	26.75
Ubrique	82.46	3.43	22.69	20.25
Vejer De La Frontera	268.46	11.32	50.78	39.73
Villaluenga Del Rosario	11.92	0.32	2.29	1.76
Villamartin	161.19	5.11	34.68	30.81
Zahara	31.89	0.93	7.94	7.03

3.2.3 Sources in Morocco

The Moroccan Department of the Environment published an environmental monograph[7] for the north-west region of Morocco including the provinces of Tanger-Assilah and Tetouan, which are the closest parts of Morocco to Gibraltar. The emissions estimates are for the year 1996. Table 8 lists the total annual emissions of oxides of nitrogen, sulphur dioxide and total suspended particulate matter for the two provinces.

Table 8: Emissions from Tanger-Assilah and Tetouan, 1996

Province	Emissions, tonnes per year								
	SOx			NOx			Total suspended particulate		
	Industry	Transport	Total	Industry	Transport	Total	Industry	Transport	Total
Tanger	7100	700	7800	270	10700	10970	380	430	810
Tetouan	4000	600	4600	150	8200	8350	220	320	540

The monograph indicates that sulphur dioxide emissions were predicted to increase by 42% by 2005; similarly, oxides of nitrogen and suspended particulate matter were predicted to increase by 30% and 35% respectively.

The monograph identifies the following major industrial sources in Tanger and Tetouan:

- Thermal power stations at Tanger and Tetouan;
- Cement works at Tanger and Tetouan;
- Sugar refineries at Tetouan, Ksar El Kebir and Larache.

The two power stations are relatively small (<60MW) oil fired units. In addition, there is a larger (385 MW) new combined cycle gas turbine unit fuelled by natural gas at Tahaddarrt. This is unlikely to emit significant quantities of particulate matter or sulphur dioxide, but will add to the emissions of oxides of nitrogen.

3.3 Dispersion modelling

3.3.1 The dispersion model

A dispersion model ADMS-4.1 was used to predict ground level concentrations of oxides of nitrogen, carbon monoxide and sulphur dioxide. ADMS-4.1 is a PC-based model of the dispersion in the atmosphere of passive, buoyant or slightly dense continuous or finite duration releases from single or multiple sources. It is a state of the art dispersion model in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and heat flux at the surface. Concentration distributions are Gaussian in stable and neutral conditions, but the vertical distribution is non-Gaussian in convective conditions to take account of the skewed structure of the vertical component of turbulence. The model contains a meteorological preprocessor that calculates the required boundary layer parameters from a variety of meteorological input data. The model can be used to calculate mean concentrations and concentration percentiles for averaging times ranging from seconds to a year. The model contains modules for predicting the influence of plume rise, terrain and buildings on dispersion.

3.3.2 Nearby major industrial sources in Spain

The major industrial sources in Spain, identified in Table 6 were modelled as individual point sources. The emissions for 2006 were modelled, also assuming that the plant operated continuously throughout the year. Details of the discharge conditions, stack heights and diameters were not available, although photographs of the industrial plant showed that the emissions were discharged through high stacks. The industrial point sources were therefore modelled for a range of stack heights in the range 50-150

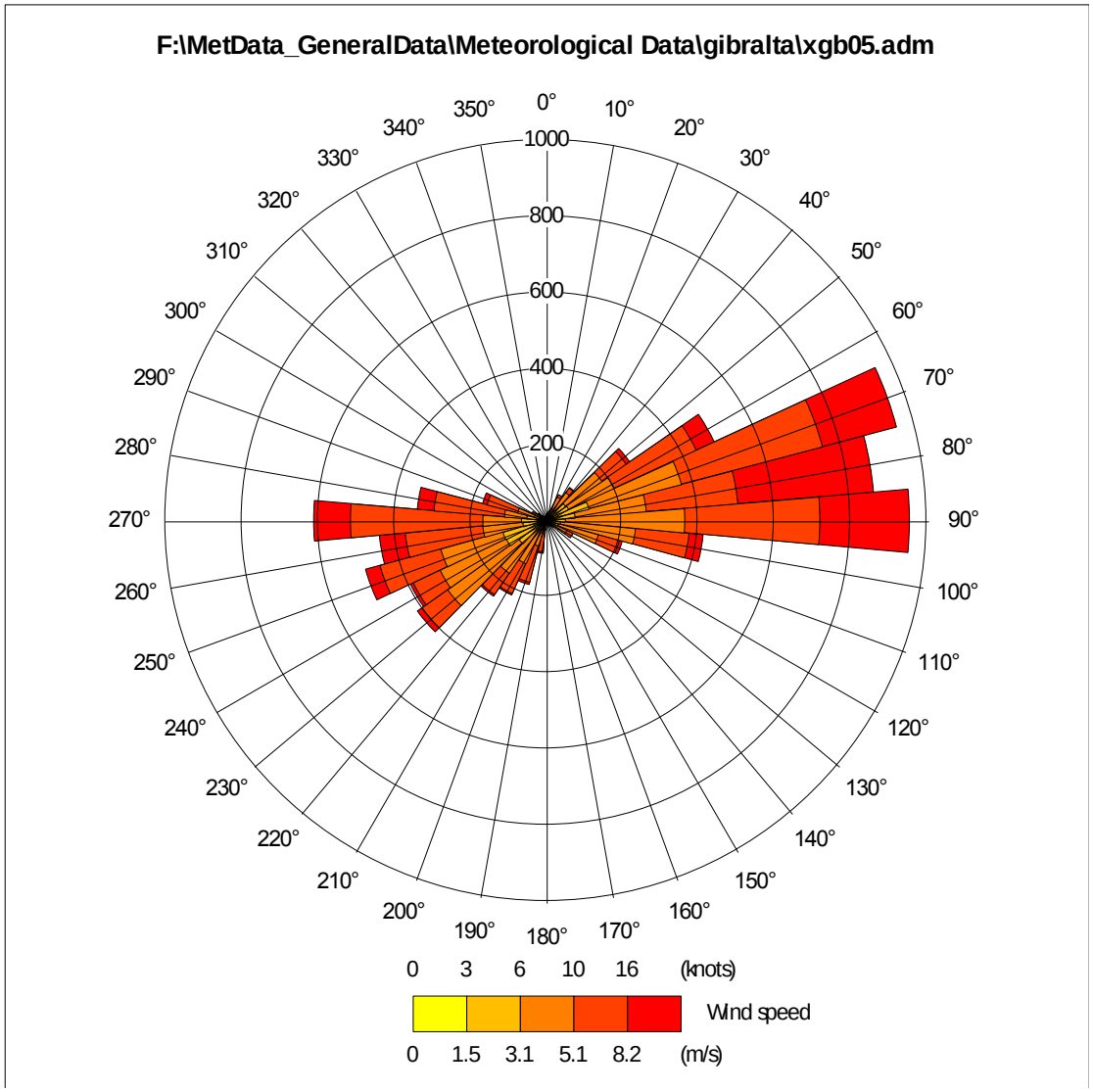
[7] http://www.minenv.gov.ma/onem/synt_monog_regionales/Syn_Nord_ouest.pdf

m in order to assess the sensitivity of the predictions to the stack height. Default discharge velocities of 15 m s^{-1} and discharge temperatures of 100°C were used for each stack.

The model took into account the complex terrain in Gibraltar and southern Spain. An area of 32' longitude by 32' latitude was extracted from the United States Geological Survey Digital Elevation Model at 30'' resolution (approximately 900 m). The surface roughness of sea areas was assumed to be 0.001 m while land areas were assumed to have a surface roughness of 1 m.

Meteorological data for the period 2002-2006 for Gibraltar Airport was obtained from Trinity Consultants. The data provides hourly sequential records of the wind speed and direction, temperature and cloud cover. Fig.2 shows a windrose for 2005. The winds are predominantly from the ENE and WSW directions with typical wind speeds of 5-8 m s^{-1}.

Fig. 2: Windrose from Gibraltar airport, 2005



3.3.3 Other sources in Spain

The emissions from the municipalities listed in Table 7 were modelled as 1 km square area sources. The surface roughness of the area was assumed to be 1 m. The emissions from the large industrial sources were subtracted from the emission totals to avoid double counting. Hourly sequential meteorological data from Gibraltar airport for 2006 was used in the analysis.

3.3.4 Sources in Morocco

The emissions from Morocco were modelled, conservatively, as two ground level point sources at Tetouan and at Tanger. The vertical discharge velocity was assumed to be zero and the discharge was assumed to be at ambient temperature. Hourly sequential meteorological data from Gibraltar airport for 2006 was used in the analysis. The surface roughness of the sea area between North Africa and Gibraltar was assumed to be 0.001 m.

3.4 Model results

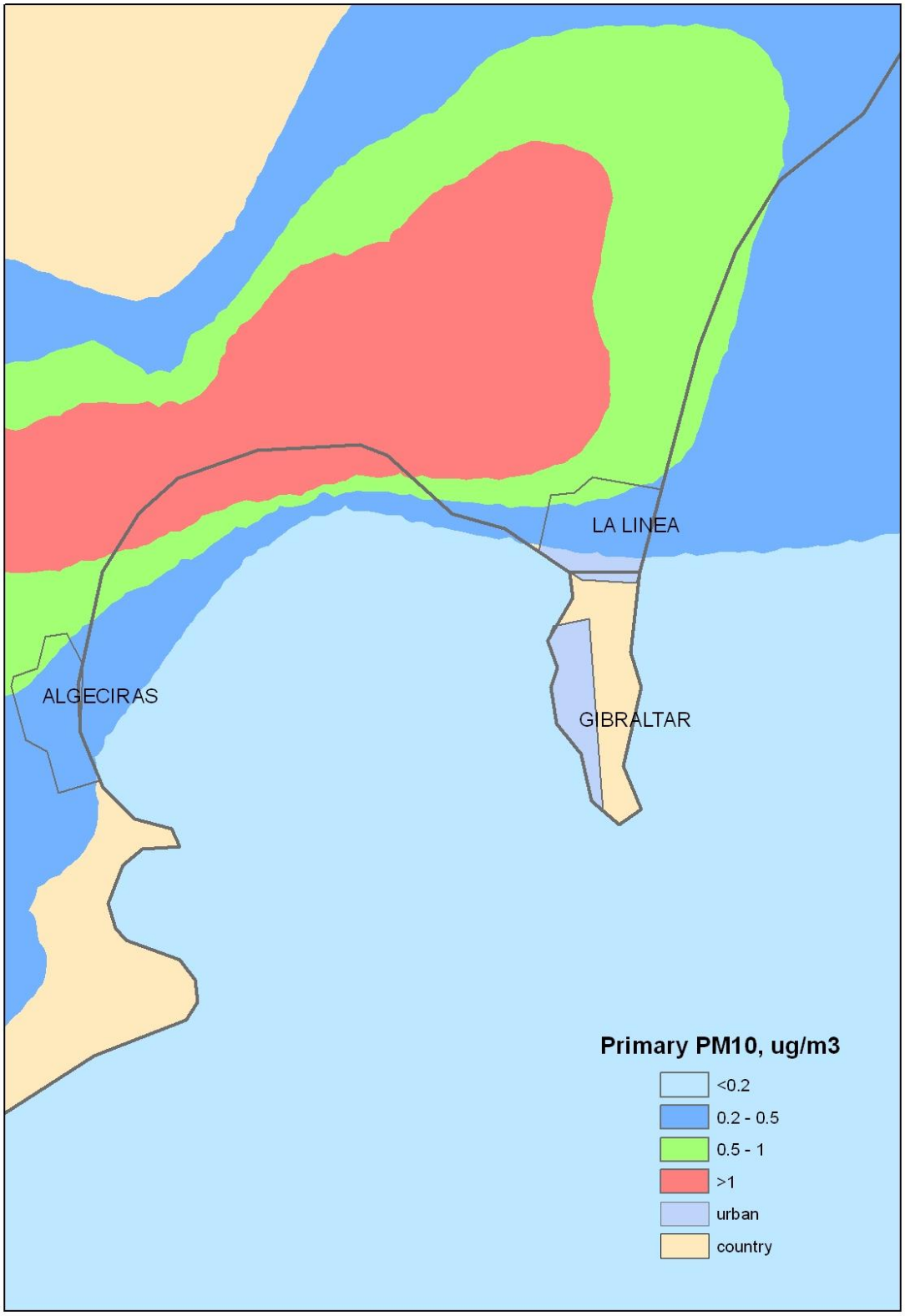
3.4.1 Nearby large industrial sources in Spain

Fig.3 shows the contribution to PM_{10} concentrations from emissions from large industrial sources identified in Table 6. The modelling assumed that the stack height for each source was 50 m in order to provide a conservative overestimate of the contribution to concentrations in Gibraltar. The modelling was based on meteorological data for 2006. Table 9 lists the modelled contribution to annual mean concentrations at Rosia Road and Bleak House.

Table 9: Modelled contribution from nearby large point sources in Spain

Pollutant	Site	Modelled contribution to annual mean concentration, μg m^{-3}				
	Stack height	50 m			100 m	150 m
	Year	2006	2005	2004	2006	
PM_{10}	Rosia Road	0.04	0.08	0.08	0.02	0.01
	Bleak House	0.01	0.03	0.03	0.01	<0.005
NOx	Rosia Road	0.13	0.25	0.23	0.09	0.05
	Bleak House	0.04	0.06	0.10	0.03	0.01
SO2	Rosia Road	0.77	1.90	1.86	0.52	0.27
	Bleak House	0.18	0.55	0.68	0.11	0.06
Ni	Rosia Road		2.65×10^{-5}			
	Bleak House		6.24×10^{-6}			

Fig.3: Contribution to annual mean PM_{10} concentrations from primary emissions from nearby industrial sources in Spain



3.4.2 Other nearby sources in Spain

Table 10 shows the modelled contribution from other nearby emission sources in Spain to concentrations at Rosia Road and Bleak House.

Table 10: Modelled contribution to annual mean concentrations from other nearby sources in Spain

Site	Contribution to annual mean concentrations, μg m^{-3}			
	PM_{10}	$PM_{2.5}$	NO_x	SO2
Rosia Road	0.35	0.33	1.30	0.20
Bleak House	0.19	0.18	0.72	0.12

3.4.3 Sources in Morocco

Table 11 shows the modelled contribution from nearby emission sources in Morocco to concentrations at Rosia Road and Bleak House.

Table 11: Modelled contribution to annual mean concentrations from nearby sources in Morocco

	Contribution to annual mean concentrations, μg m^{-3}		
	PM_{10}	NO_x	SO_2
Rosia Road	0.11	1.31	1.05
Bleak House	0.12	1.51	1.21

3.5 Discussion

The emissions from the following sources were modelled:

- Nearby major industrial sources in Spain;
- Other nearby sources in Spain;
- Nearby sources in Morocco.

Of these the nearby major industrial sources in Spain potentially make the largest contribution to pollutant concentrations in Gibraltar. Details of the discharge conditions and stack heights for the industrial plant were not available and so the modelling has been carried out for a range of stack heights (50 –150 m) in order to estimate the sensitivity of the model predictions to the assumed stack height. Increasing the stack height from 50 m to 150 m reduced concentrations at Rosia Road, Gibraltar by a factor of approximately 2. Modelling with meteorological data for different years (2004-2006) had a small effect on the modelled concentrations at Rosia Road and Bleak House.

The maximum modelled contribution to concentrations at Rosia Road from primary PM_{10} emissions from the nearby major industrial plants in Spain was less than 0.1 μg m^{-3} as an annual mean for a stack height of 50 m: this is an overestimate because the actual stacks for the largest sources are rather taller.

The total contribution to primary PM_{10} concentrations from the modelled nearby sources in Spain and Morocco was 0.52 μg m^{-3} at Rosia Road. This may be compared with the primary contribution modelled by EMEP of 2.7+0.1 =2.8 μg m^{-3} shown in Table 5. It is concluded that there is no substantial local enhancement of primary PM_{10} concentrations.

A small percentage (~5%) of the emissions of sulphur oxides from industrial combustion plant are present initially as sulphur trioxide, which quickly reacts with water vapour to create sulphuric acid aerosol. Assuming that 5% of the emissions are initially as sulphur trioxide that forms sulphuric acid aerosol in the atmosphere, the maximum predicted contribution from this source to secondary PM_{10} concentrations at Rosia Road is 0.12 μg m^{-3} as an annual mean. This may be compared with the contribution from sulphate modelled by EMEP of 3.4 μg m^{-3} shown in Table 5. It is concluded that there is no substantial local enhancement of secondary PM_{10} concentrations.

Summing all the modelled contributions (primary and secondary), the total contribution from nearby sources in Spain and Morocco is estimated to be 0.6 μg m^{-3} as an annual mean at Rosia Road and 0.4 μg m^{-3} as an annual mean at Bleak House. This is small compared with the measured annual mean PM_{10} concentration at the Rosia Road roadside site in Gibraltar of 39.8 μg m^{-3} in 2006 (2007: 44.8 μg m^{-3}. 2008: 39.4 μg m^{-3})

The largest individual modelled source of sulphur dioxide and particulate matter was the UPT power station at Los Barrios. Work on the construction of a flue gas desulphurisation plant commenced in 2006 with expected completion date 2008. The flue gas desulphurisation plant will substantially reduce sulphur and particulate emissions by approximately 90 % and 50 % respectively, further reducing the contribution to particulate concentrations in Gibraltar.

4 Conclusions

The EMEP model predicts that transboundary pollution contributed 2.8 μg m^{-3} to annual mean primary PM_{10} concentrations and 5.4 μg m^{-3} to annual mean secondary inorganic PM_{10} concentrations in Gibraltar in 2006. These values are small compared with the measured concentration at the Rosia Road monitoring site of 39.8 μg m^{-3} in 2006. It is concluded that the transboundary sources modelled by the EMEP model only contribute a relatively small part of the total concentration at the 50 km spatial resolution of the model.

The EMEP model does not provide estimates of the contribution from secondary organic aerosol and resuspended and wind-eroded mineral dust. The contribution from resuspended and wind-eroded mineral dust will be determined experimentally by analysis of particulate matter collected by samplers at the monitoring stations in Gibraltar and is the subject of a separate report. There are no measurements of secondary organic aerosol concentrations in Gibraltar and few in Spain. Measurements in Madrid indicated that daily average secondary organic aerosol concentrations were typically approximately 1 μg m^{-3} during high concentration episodes. Concentrations in Gibraltar are likely to be similar an so it is concluded that secondary organic aerosols do not make a substantial contribution to PM_{10} concentrations in Gibraltar.

The EMEP model only provides predictions of pollutant concentrations at a spatial resolution of 50 km. The concentration in each 50 km square is approximately the average concentration and the concentrations will be higher near local sources within the 50 km square. The contributions from sources near Gibraltar in the Spanish province of Cadiz and in northern Morocco were assessed using the ADMS4.1 dispersion model. The local sources taken into account included CEPSA refinery and the UPT power station. The total contribution from nearby sources in Spain and Morocco was estimated to be 0.6 μg m^{-3} as an annual mean at Rosia Road and 0.4 μg m^{-3} as an annual mean at Bleak House. This is small compared with the measured annual mean PM_{10} concentration at the Rosia Road roadside site in Gibraltar of 39.8 μg m^{-3} in 2006. It was concluded that nearby sources of emission in Spain and Morocco do not make a substantial contribution to PM_{10} concentrations in Gibraltar.

AEA group
329 Harwell
Didcot
Oxfordshire
OX11 0QJ

Tel: 0870 190 6401
Fax: 0870 190 6318