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Atmospheric Dispersion Modelling of Nickel in the Swansea Area

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Executive Summary

Exposure to air pollutants in ambient air can have an adverse effect on human health. In response, the European Union has developed an extensive body of legislation which has established health based standards and objectives for a number of pollutants in air. The Fourth Air Quality Directive established a target value for nickel of 20 ng m^{-3}, as an annual mean concentration, to enter into force on the 1^{st} January 2012.

The National Physical Laboratory (NPL), on behalf of the Department of Environment, Food and Rural Affairs, operates and manages the UK Heavy Metals monitoring network. The network has recently been restructured to meet the requirements of the Fourth Air Quality Directive and currently comprises 24 sites. There are network sites in Swansea and Cardiff and one of the pollutants monitored is nickel. The annual mean concentrations of nickel at the Swansea site (26.1 ng m^{-3} in 2006) are higher than that those determined at the Cardiff site (3.8 ng m^{-3} in 2006), indicating local sources contributing to the observed concentrations in the Swansea area.

The nickel refinery operated by Vale Inco at Clydach, a few miles to the north east of Swansea, is a significant source of nickel in the area and in the UK. This report describes a dispersion modelling study to calculate the concentrations of nickel in the Swansea area. The specific aims of the study were:

(1) to compare the modelled concentrations with those that were measured, and hence to determine the contribution of this source to concentrations in the area, and,

(2) to check that the monitoring sites were suitably located.

The ADMS-ROADS model has been used to calculate concentrations of nickel from the refinery for the 2006 using year-specific meteorology and emissions. Meteorological data was taken from the nearest observatory at Mumbles Head. As the refinery is sited in a valley and surrounded by hills, a terrain dataset was purchased and used for the domain of interest.

The key results from the study were:

- Wind roses derived from the 2006 meteorological data for Mumbles Head indicated that the most common wind directions were from the South West to West sector (230°-270°);
- The results derived using the terrain data were more realistic than model runs in which the data were not used;
- Using the <u>reported stack emissions</u> of nickel for the refinery in 2006, these process emissions contributed up to 5 ng m^{-3} to the total modelled annual mean concentration. The national assessment modelling has suggested that there could be additional, fugitive, emission sources at such facilities. Other than as a sensitivity, such emission sources were not included in the model runs;
- Comparison with the measurements made at the independent sites operated by Swansea City Council suggested that the use of measurements from the Cardiff site in the national network significantly underestimated the sources not explicitly modelled; the use of the Swansea measurements gave better agreement. The agreement was improved further if the actual weekly measurements were used rather than the derived monthly-averaged concentrations;
- As the annual mean concentration for the Swansea site was already above the target value, widespread exceedences of the target value were seen across the model domain;
- Contour plots of the modelled concentrations suggested that the four monitoring sites in the area (Coedgwilym Cemetery, INCO Europe, YGG Gellionnen and Morriston Groundhog) seem to be well located to assess the impact of the Vale Inco refinery.

The above is consistent with other UK and European modelling studies of metals in air, which also tend to underpredict observed concentrations, when using reported emissions. This could arise if the

reported emissions are too low, there are other emission sources (such as fugitive emission sources) present, or there are significant contributions from processes, such as resuspension or volatilisation of particulate material from the surface, which are not treated in the ADMS-ROADS model.

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1 Introduction

Exposure to air pollutants in ambient air can have an adverse effect on human health. In response, the European Union has developed an extensive body of legislation which has established health based standards and objectives for a number of pollutants in air. In particular, the Fourth Air Quality Directive [EC, 2004] established a target value for nickel of 20 ng m^{-3}, as an annual mean concentration, to enter into force on the 1^{st} January 2012.

The directive specifies a number of elements related to the

- assessment of ambient air quality through monitoring, modelling, and objective estimation
- management of air pollution
- public information
- reporting of assessment results

On behalf of the Department of Environment, Food and Rural Affairs, NPL operates and manages the UK Heavy Metals monitoring network. In 2006, the network comprised 17 sites [Brown *et al.*, 2007]. It has since been restructured to meet the requirements of the Fourth Air Quality Directive [EC, 2004]. The open sites in 2006 are listed in Table 1-1.

Table 1-1: Sites in the UK Heavy Metals Monitoring Network.

Site Code: Site Name	Site Type
46: IMI Refiners Ltd, Walsall	Industrial Background
47: BZL Ltd, Avonmouth	Industrial Background
49: INCO Europe, Swansea	**Industrial Background**
56: BZL Ltd, Avonmouth, Hallen Village	Industrial Background
58: Avesta Steel, Sheffield	Industrial Background
59: ICI Weston Point, Runcorn	Industrial Background
60: London Brent, North Circular	Roadside
61: London, Cromwell Road	Roadside
62: London, Horseferry Road	Urban Background
63: Leeds, Old Market Buildings	Urban Background
64: Glasgow, St Annes Primary School	Urban Background
65: Eskdalemuir, Met Office	Rural
66: Motherwell, Civic Centre	Urban Background
67: Manchester M56, Junction 4	Roadside
68: Cardiff, Waungron Road	**Roadside**
69: Brookside Metals, Bilston Lane, Walsall	Industrial Background
70: Elswick 6, Newcastle Upon Tyne	Industrial Background

As part of the monitoring programme, particulate samples are taken at all sites in the Network using Partisol 2000 instruments (fitted with PM_{10} heads) operating at a calibrated flow rate of 1 m^3 hr^{-1} in accordance with EN 12341:1998. Samples are taken on 47 mm diameter GN Metricel membrane filters. Analysis for particulate-phase metals takes place at NPL with a Perkin-Elmer Elan DRC II ICP-MS, using NPL's UKAS-accredited procedure, which is fully compliant with the requirements of EN 14902:2005.

There are network sites in Swansea and Cardiff and one of the pollutants monitored is nickel. The annual mean concentrations of nickel at the Swansea site (26.1 ng m^{-3} in 2006) are higher than that those determined at the Cardiff site (3.8 ng m^{-3} in 2006), indicating local sources contributing to the observed concentrations in the Swansea area.

One of the significant sources of nickel in the UK is the nickel refinery operated by Vale Inco at Clydach[1], a few miles to the north east of Swansea. This report describes a dispersion modelling

[1] Formerly, INCO Europe. INCO Europe is used in the report as one of the monitoring locations is called INCO Europe.

study to calculate the concentrations of nickel in the Swansea area. The specific aims of the study were:

(1) to compare the modelled concentrations with those that were measured, and hence to determine the contribution of this source to concentrations in the area, and,

(2) to check that the monitoring sites were suitably located.

2 The ADMS-ROADS Dispersion Model and Input Data

2.1 The Model

The study made use of the ADMS ROADS dispersion model (version 2.3), developed by Cambridge Environmental Research Consultants (http://www.cerc.co.uk/software/admsroads.htm). ADMS ROADS is an advanced dispersion model for investigating air pollution problems due to industrial sites and networks of roads. The model has been extensively used in regulatory applications in the United Kingdom and elsewhere [see references within the ADMS ROADS User Guide (CERC, 2006)].

The model contains an interface to ESRI's ARCGIS Geographic Information System, allowing the model to be run from ARCGIS and the model results to be presented as pollutant concentration contours superimposed on a map of the area of interest.

2.2 The Model Domain

A map of the Swansea area is shown in Figure 2-1.

Figure 2-1: Ordnance Survey map of the Swansea area with the model domain (black square) and the locations of the source (red circle), monitoring sites (green squares) and meteorological station (black circle) superimposed. The Ordnance Survey map is © Crow n Copyright (2008).

Superimposed on the map are:

- The location of the nickel refinery at Clydach (red circle, grid co-ordinates 269391,201244)
- The model domain (black square), which extended ±10 km from the source. The model domain was defined by the grid co-ordinates: lower left (258900,191300), upper right (278900,211300).
- The locations of 4 monitoring sites (green squares), operated either as part of the Defra national monitoring programme or by the local council:
  - INCO Europe, Glais (map ref: 270245,200475)
  - Coedgwilym Cemetery, Pontardawe (map ref: 270907,202100)
  - YGG Gellionnen (map ref: 269240,201914)
  - Morriston, Swansea (map ref: 267168,197593)

➢ The location of the meteorological station at Mumbles Head (black circle, grid reference 262700, 187000).

Figure 2-2 shows an expanded view of the central area of the map and the locations of the source and monitoring sites.

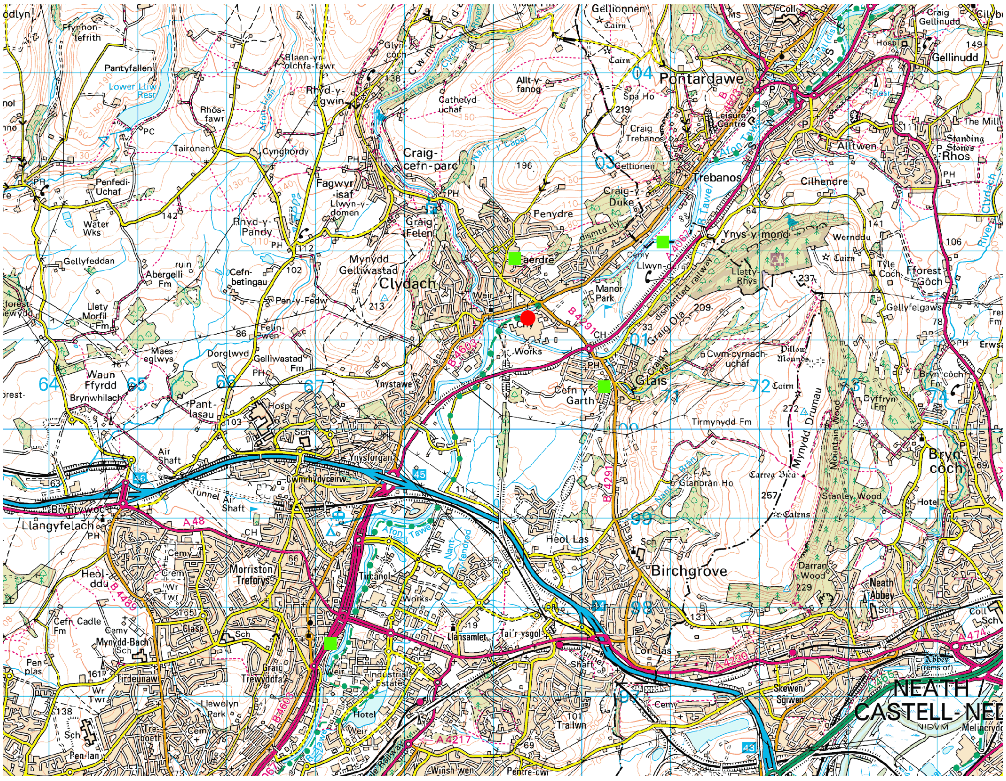

Figure 2-2: Expanded view of the central area showing the locations of the source (red circle) and monitoring sites (green squares). The Ordnance Survey map is © Crown Copyright (2008).

2.3 Input Data

The dispersion model requires data on:

- the characteristics of the emission source
- the nickel emissions (magnitude and temporal profile)
- background nickel concentrations
- meteorology
- the terrain (in this case)

These are described further in the following sections.

2.3.1 Characteristics of the Vale Inco Nickel Refinery

Tom Price (Swansea City Council) provided the following information on the stack at the nickel refinery:

- stack height = 100 m
- stack diameter = 1.8 m
- stack exit flow = 33.06 $m^3\ s^{-1}$

The exit temperature of the stack was assumed to be 100 °C.

2.3.2 Nickel Emissions from the Vale Inco Nickel Refinery

There are a number of sources of information on air pollution from industrial facilities:

- The National Atmospheric Emission Inventory (NAEI)[2]
- The Environment Agency[3] (The Vale Inco Refinery has the authorisation licence BL4567IZ)
- The European Environment Agency's European Pollutant Emission Register (EPER)[4]

The reported annual nickel emissions available from the above sources for the refinery at Clydach are presented in Table 2-1. The NAEI data show a large change between 2004 and 2005. On comparison with the other emission estimates, it is clear that the 2005 NAEI estimate is misreported.

Table 2-1: Annual Nickel Emissions from the Vale Inco Refinery at Clydach.

Year	Annual Emission		
	NAEI	Environment Agency	EPER
2003		1984 kg	
2004	1043 kg	1043 kg	1.04 tonne
2005	1.41 kg	1413 kg	
2006		3166 kg	
2007		2971 kg	

The annual emissions for 2006 were converted into an emission in g s^{-1}. In the absence of information on the operation of the facility, it was assumed that the emissions were constant in time.

In the national assessment modelling for the 4th Daughter Directive, Vincent and Passant (2006) raised the possibility of fugitive emissions from metal processing plants. These were highly uncertain and results were presented for a sensitivity case in which the emission rates were set to three times the reported stack emissions (see Section 3.5).

2.3.3 Background Nickel Concentrations

The reported emissions from the stack were modelled explicitly. It is conventional to treat the effect of (i) more distant sources or (ii) small sources not directly modelled by adding a 'background' concentration' to the modelled concentration at each receptor point. The background concentrations were based on measurements from the monitoring sites in Swansea or Cardiff, which form part of the national network operated by NPL on behalf of the Department for Environment, Food and Rural Affairs and the Devolved Administrations. Figure 2-3 and Figure 2-4 show the actual weekly and the reported monthly-averaged concentrations of nickel in air (in ng m^{-3}) determined at the two sites during 2006 [Brown *et al.*, 2007]. The reported measurements are listed in Appendix 1.

2.3.4 Meteorological Data

The ADMS-ROADS dispersion model can calculate distributions of pollutant concentrations for the specified model domain:
(a) from hourly sequential meteorological data (and averages over the period modelled), or,
(b) for representative atmospheric dispersion conditions (such as neutral, unstable conditions).

The meteorological station at Mumbles Head (Grid reference: 262700, 187000) was the nearest station to the source. Hourly sequential meteorological data were obtained from the Met Office for this station for 2006, as the latest year then available. The dataset was supplied in a format that could be used directly in the dispersion model and contained information on the hourly variation of the following parameters:

- Station Number
- Year
- Day in Year
- Hour in Day
- Temperature (in °C)
- Windspeed (in m s^{-1})
- Wind Direction (°)
- Cloud Cover (in oktas)
- Precipitation (in mm hr^{-1})
- Relative Humidity (%)

[2] See www.naei.org.uk
[3] See http://maps.environment-agency.gov.uk/wiyby/wiybyController?extraClause=AUTHORISATION_ID*'BL4567IZ%'
[4] see http://eper.eea.europa.eu/eper/facility_details.asp?id=191176&year=2004&CountryCode=UK

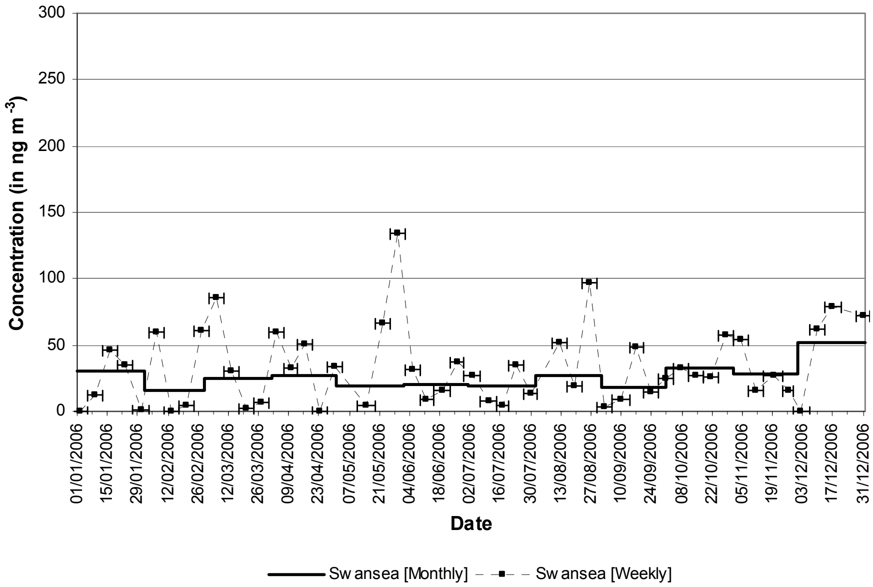

Figure 2-3: The weekly and derived monthly-averaged concentrations of nickel in air (in ng m^{-3}) as measured at the Swansea monitoring site in the Defra national programme.

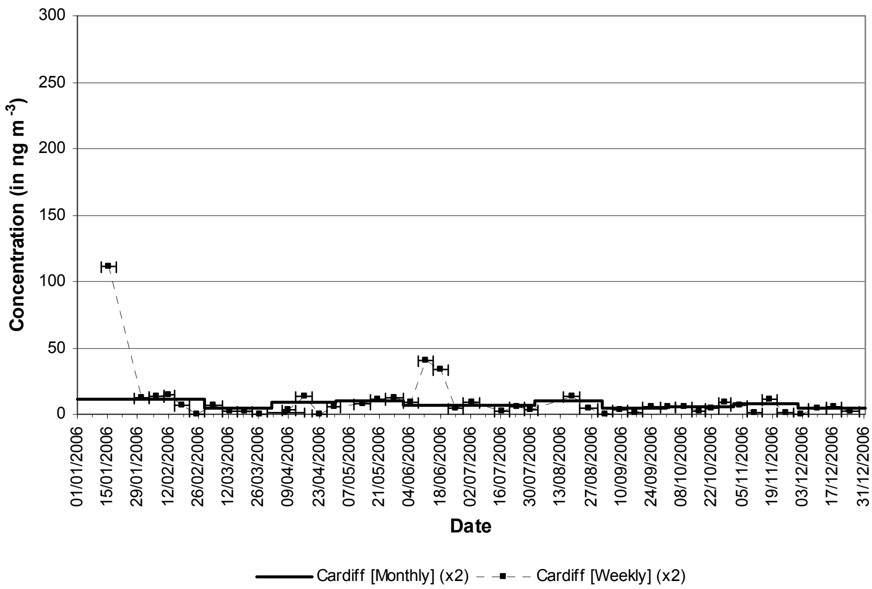

Figure 2-4: The weekly and derived monthly-averaged concentrations of nickel in air (in ng m^{-3}) as measured at the Cardiff monitoring site in the Defra national programme.

ADMS ROADS uses standard algorithms to calculate the boundary layer meteorological parameters required by the dispersion model [Holtstag and van Ulden, 1983; CERC, 2001]. In processing the data, the module checks that the input data lie within specified limits. Warning or error messages are provided as appropriate.

Figure 2-5 shows the wind rose derived for Mumbles Head from the 2006 meteorological data. As expected, the most common wind directions are from the South West to West sector (230°-270°).

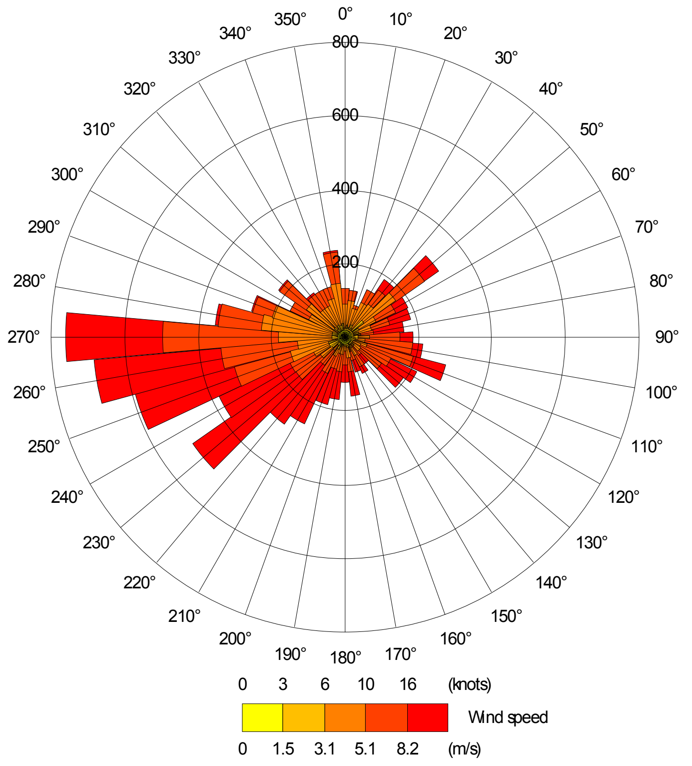

Figure 2-5: Wind Rose for Mumbles Head in 2006

Pasquill [1961] developed a method of characterising atmospheric dispersion conditions based on six representative stability classes (A-F), with class A being the most unstable or most turbulent class, and class F the most stable or least turbulent class (see Table 2-2)[5]. A seventh class (G) was subsequently added. Appendix 2 provides the meteorological conditions that define each class.

Table 2-2: The Pasquill Stability Classes

- A - very unstable
- B - unstable
- C – slightly unstable
- D - neutral
- E - slightly stable
- F - stable

A second meteorological dataset was obtained from the Met Office, which gave a monthly breakdown of the frequency (by hours and as a percentage) that these different dispersion conditions occurred in 2006 (see Appendix 3). It can be seen that neutral conditions (Class D) are the most common class, occurring 72.3% of the time. In one sense, this is not surprising as neutral conditions apply to heavily overcast skies, at any windspeed, day or night. The next most common dispersion conditions are slightly unstable (Class C, 10.4% of the time) and slightly stable (Class E, 6.6% of the time).

2.3.5 Terrain Data

The Vale Inco refinery lies in a valley. The accuracy of the dispersion model calculations can be affected in hilly areas and terrain data should be used in the model for such cases. The ADMS ROADS user guide recommends the use of terrain data if there are slopes steeper than approximately 1 in 10 [see Section 6.1 in CERC, 2006].

The ADMS ROADS model has a utility to generate the required input terrain files for the specified model domain from digital terrain data supplied by national mapping agencies such as the UK Ordnance Survey. The terrain data are provided as 5 km x 5 km tiles and the appropriate tiles were purchased for the area covered by the map in Figure 2-1.

[5] Advanced dispersion models, such as ADMS ROADS, do not categorize atmospheric turbulence by Pasquill stability classes. These models use some form of Monin-Obukhov similarity theory.

3 Model Results

The model runs undertaken are listed in Table 3-1 with the key assumptions made. Concentrations were calculated for both short-term (i.e., hourly) and long-term (i.e., annual) exposure.

3.1 Effect of Terrain

Figure shows contour maps of the modelled annual mean concentration of nickel for runs undertaken with and without terrain data (Runs 1 and 2 in Table 3-1). In the absence of terrain data, the model assumes that there are no topographical effects.

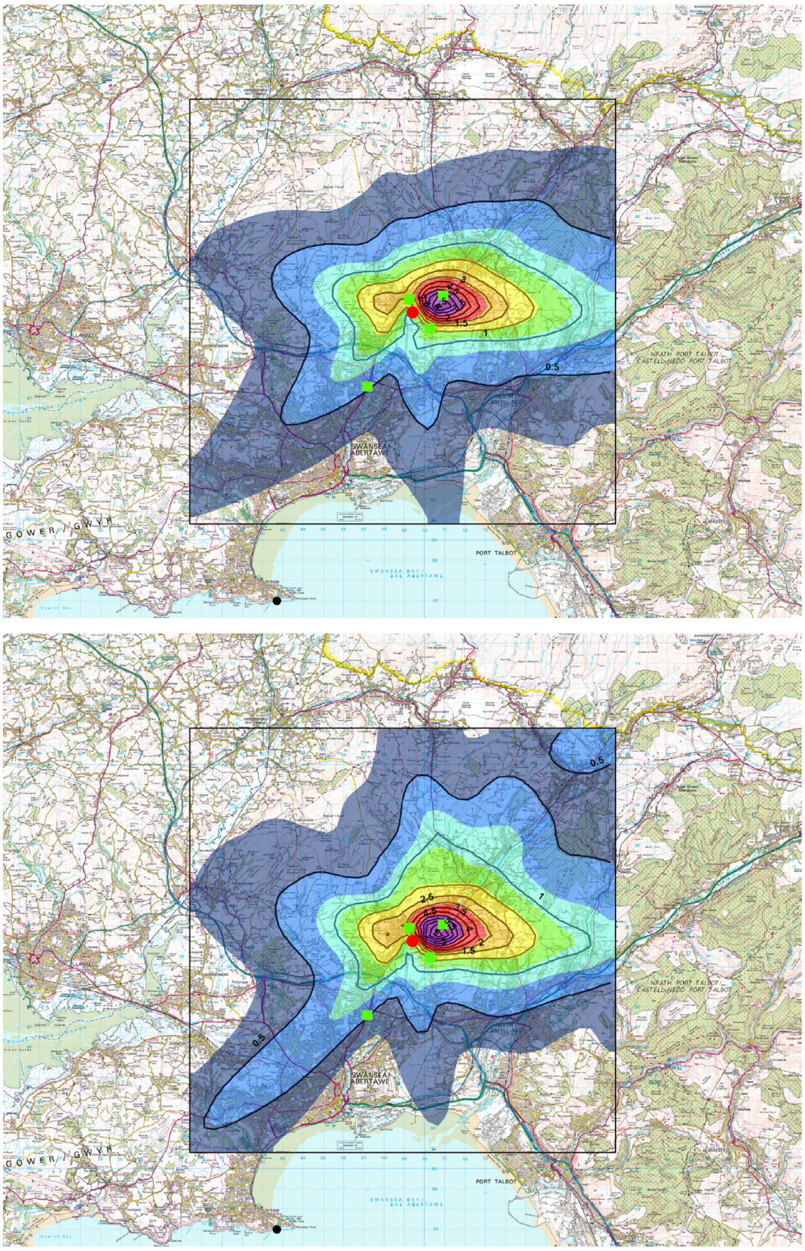

Figure 3-1: The modelled concentrations of nickel (in ng m^{-3}) for the Source-only runs in which no terrain data (upper panel) or terrain data (lower panel) were used.

The influence of the terrain data can be seen by comparing the upper and lower panels of Figure 3-1. In the absence of terrain data, the modelled concentrations reflect the most frequent wind directions observed in the wind rose (see Figure 2-5). The highest concentration region is to the north-east of the source, as would be expected with the prevailing wind from the south west.

Table 3-1: Overview of ADMS Model Runs and Model Assumption.

Run	Emissions	Meteorology	Background	Terrain	Output
1. Source only	3166 kg	2006 Hourly	No	No	ST/LT
2. Source only	3166 kg	2006 Hourly	No	Yes	ST/LT
3. Source+Cardiff Background – 1	3166 kg	2006 Hourly	Cardiff (Monthly)	No	ST/LT
4. Source+Cardiff Background – 1	3166 kg	2006 Hourly	Cardiff (Monthly)	Yes	ST/LT
5. Source+Cardiff Background – 2	3166 kg	2006 Hourly	Cardiff (Weekly)	No	ST/LT
6. Source+Cardiff Background – 2	3166 kg	2006 Hourly	Cardiff (Weekly)	Yes	ST/LT
7. Source+Swansea Background - 1	3166 kg	2006 Hourly	Swansea (Monthly)	No	ST/LT
8. Source+Swansea Background - 1	3166 kg	2006 Hourly	Swansea (Monthly)	Yes	ST/LT
9. Source+Swansea Background - 2	3166 kg	2006 Hourly	Swansea (Weekly)	No	ST/LT
10. Source+Swansea Background - 2	3166 kg	2006 Hourly	Swansea (Weekly)	Yes	ST/LT
11. Stability Class Runs	3166 kg	default	Fixed	No	ST
12. Stability Class Runs	3166 kg	default	Fixed	Yes	ST

Note: Short-term (ST)/Long-term (LT) indicates that output was provided as concentrations for each line or hour in the input data (ST) or as an average over the period covered by the input data (LT, which corresponds to an annual mean in this case).

The spatial pattern is shifted in the model runs, in which terrain data have been used. The airflow is modified in the presence of the hills and valleys can be seen on the eastern side of the model domain. All the results presented subsequently will be based on model runs, in which the terrain data have been used.

3.2 Annual Mean Concentrations

For the calculations undertaken using the 2006 hourly sequential meteorological data, the long-term concentration is equivalent to the annual mean concentration. These are calculated for both the grid points in the model domain and the specified receptor locations (see section 2.2).

The annual mean concentrations for the 4 receptor sites and the grid origin are presented in Table 3-2 for the model runs (runs 2, 4, 6, 8 and 10 in Table 3-1), using terrain data and different background concentrations data (none, Cardiff weekly/monthly[6], Swansea weekly/monthly). The table also includes the observed annual mean concentrations at the national monitoring sites in Swansea and Cardiff in 2006 [Brown *et al.*, 2007].

Table 3-2: Annual Mean Nickel Concentrations (in ng m^{-3}) calculated at Specified Receptor Sites.

Site	Observed Annual Mean Concentration (in ng m^{-3})	Modelled Annual Mean Concentration (in ng m^{-3})					
		Background Period Run	None - 2	Cardiff Monthly 4	Cardiff Weekly 6	Swansea Monthly 8	Swansea Weekly 10
INCO Europe	-		1.53	5.35	8.70	28.00	36.98
Coedgwilym Cemetery	-		5.32	9.25	12.60	31.91	40.88
YGC Gellionnen	-		2.93	6.76	10.11	29.42	38.39
Morriston Groundhog	-		0.49	4.25	7.59	26.90	35.88
Grid Origin	-		0.33	4.09	7.44	26.75	35.72
Swansea (Defra)	26.13						
Cardiff (Defra)	3.76						

Notes: *Weekly* refers to the actual measurements. *Monthly* refers to the monthly-averaged concentrations derived from the weekly measurements with the individual measurements weighted by its uncertainty.

Run 2, using no background concentrations, is effectively the process contribution from the refinery alone. This shows that the modelled concentrations range from 0.33 at a location well to the south west of the refinery to a maximum of 5.32 ng m^{-3} at Coedgwilym Cemetery. The ordering of the sites - Coedgwilym Cemetery > YGC Gellionnen > INCO Europe > Morriston Groundhog - reflects the proximity and orientation to the source, as indicated in Figure 2-2 earlier and Figure 3-2 subsequently. The modelled concentrations are higher when using the individual weekly measurements compared to monthly-averaged concentrations derived from the same weekly measurements (by ~3.3 ng m^{-3} for the Cardiff measurements and ~9 ng m^{-3} for the Swansea measurements). It is clear that the use of the Cardiff measurements as background concentrations does not account for all the sources as the modelled concentrations are between 33-50% of the annual mean concentration derived from the Swansea measurements.

One further point to note is that the annual mean concentration for the Swansea site is already above the target value. As a result, the modelled concentrations at the 4 monitoring sites exceeded the target value of 20 ng m^{-3}, as an annual mean concentration.

A contour map of the modelled annual mean nickel concentrations is shown in Figure 3-2 for the model runs using the Swansea 'weekly' background measurements. The highest concentrations are to the east of the refinery source and close to the Coedgwilym Cemetery monitoring site (*i.e.*, downwind of the prevailing winds). Again, the target value is exceeded across the entire model domain for this case.

[6] *Weekly* refers to the actual measurements. *Monthly* refers to the monthly-averaged concentrations derived from the weekly measurements with the individual measurements weighted by its uncertainty.

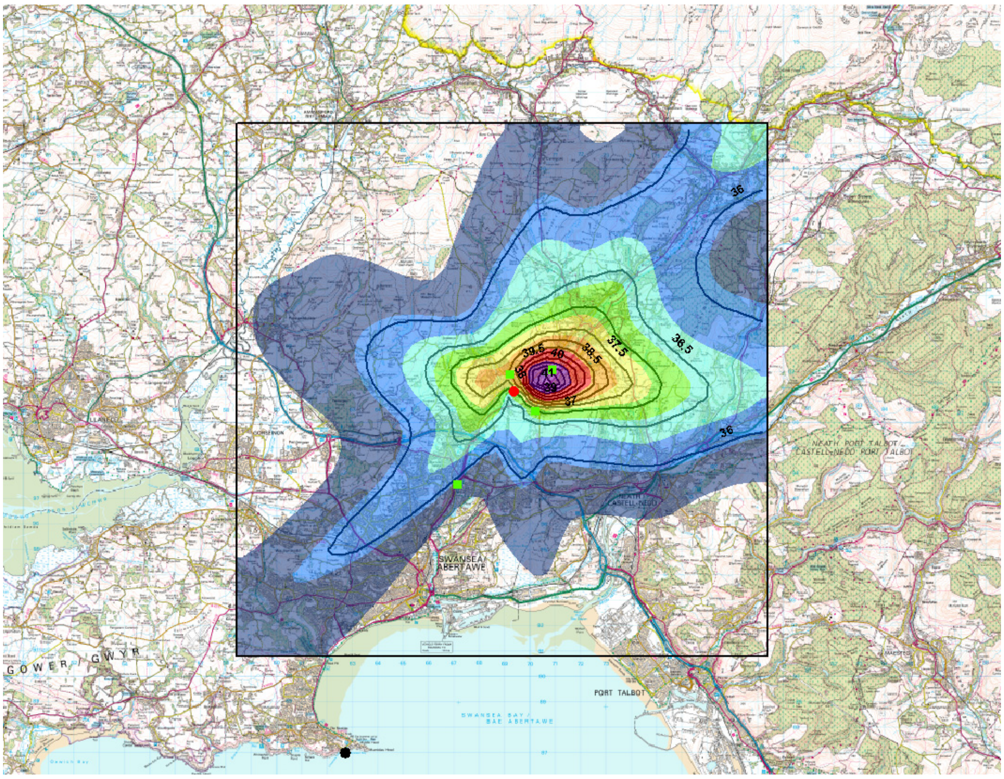

Figure 3-2: Contour map of the modelled annual mean concentrations (in ng m^{-3}) for the model run using terrain data and Swansea 'weekly' background measurements.

3.3 Comparison with Measurements

In addition to the measurements in the national monitoring programme (see Section 2.3.3 and Appendix 1), weekly measurements were made from July 2006 at two sites operated by the local authority (Coedgwilym Cemetery and Morriston Groundhog). The measurements made are shown in the upper panels of Figure 3-3 and are also listed in Appendix 4. The site at Coedgwilym Cemetery, which is both closer to and downwind from the refinery, generally has the higher concentrations. There are occasions when the converse is the case, indicating winds from the east. These measurements were used for comparison with the modelled concentrations.

The modelled short-term (*i.e.*, hourly) concentrations at these two sites were averaged over the same sampling periods as those of the measurements. A comparison of the observed and modelled concentrations is shown in the top and middle panels of Figure 3-3 for the Coedgwilym Cemetery and Morriston Groundhog sites, respectively. The black and grey bars are the modelled concentrations for the calculations with and without terrain (again, there is little impact on the modelled concentrations). The measurements made at the Coedgwilym Cemetery and Morriston Groundhog sites are shown in both panels for ease.

In Figure 3-3, there is evidence of elevated nickel concentrations at both the Coedgwilym Cemetery and Morriston Groundhog sites in December 2006. This could be indicative of poor dispersion conditions at this time. In the bottom panel of Figure 3-3, the differences in the modelled and observed concentrations between the two sites are shown to illustrate more clearly the potential contribution of the refinery. In this case, the blue symbols and line shows which is the upwind site. The wind direction has a value of '50' for prevailing winds from the south west (i.e., Morriston Groundhog is upwind of Coedgwilym Cemetery) and '0' for winds from the east.

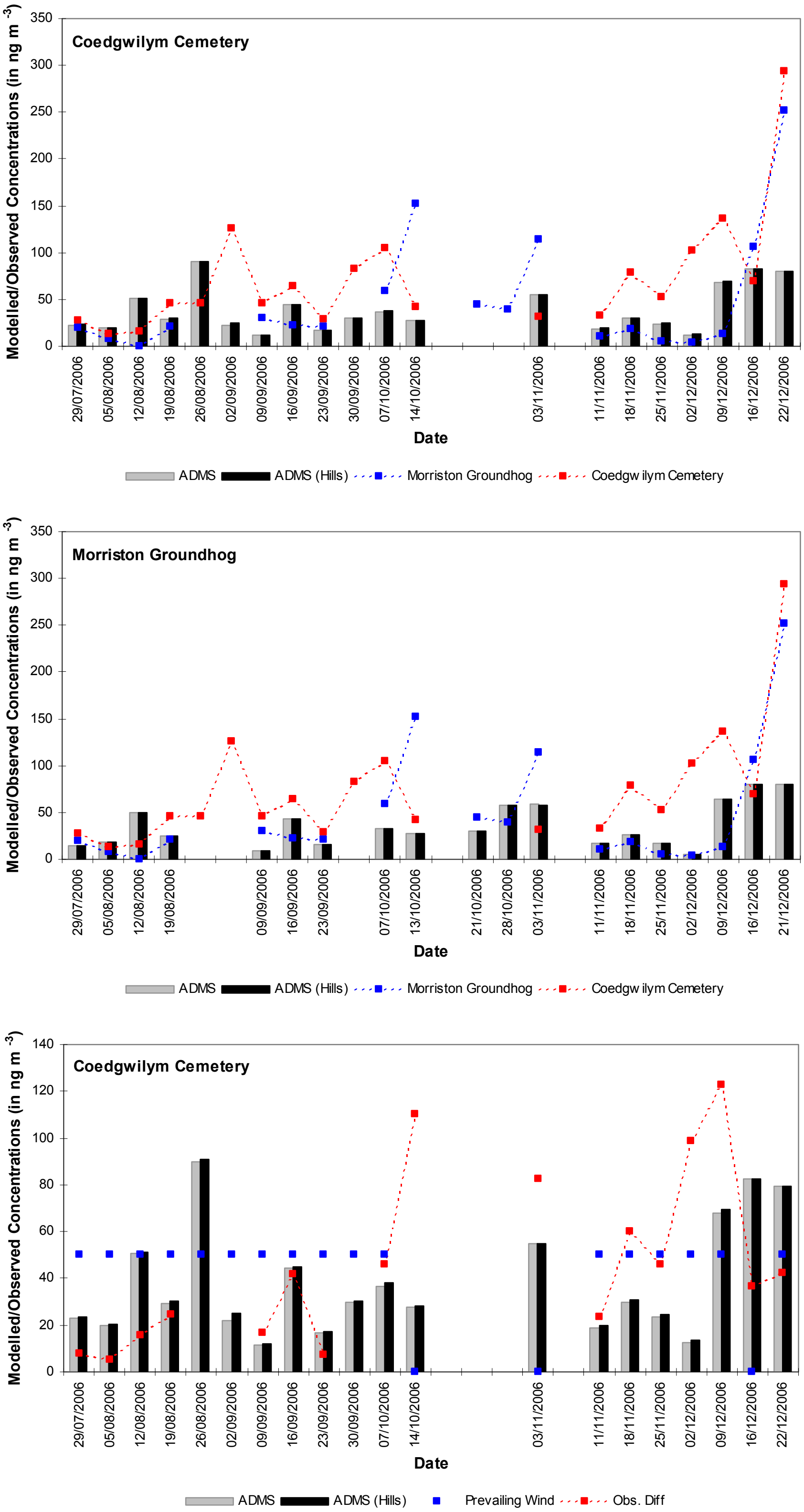

Figure 3-3: The top and middle panels show comparisons of the observed (red squares: Coedgwilym Cemetery; blue squares: Morriston Groundhog) concentrations (in ng m^{-3}) and the modelled concentrations (grey bars: without hills; black bars: with hills) for Coedgwilym Cemetery and Morriston Groundhog, respectively. The bottom panel shows the differences in the modelled and observed concentrations between the Coedgwilym Cemetery and Morriston Groundhog sites. The wind direction is shown as '50' for the prevailing winds from the south west (i.e., Morriston Groundhog is upwind of Coedgwilym Cemetery) and '0' for the reverse.

The panels in Figure 3-3 also indicate that there are periods, generally when concentrations are low, when the modelled concentrations and observed concentrations agree reasonably well but in general, the modelled concentrations are lower than those observed. This can also be seen in the scatter plots of the modelled against the observed concentrations for the two sites. Scatter plots are shown for both the model runs using the 'weekly' and 'monthly' background concentrations. The model runs using the 'weekly' dataset give the better description.

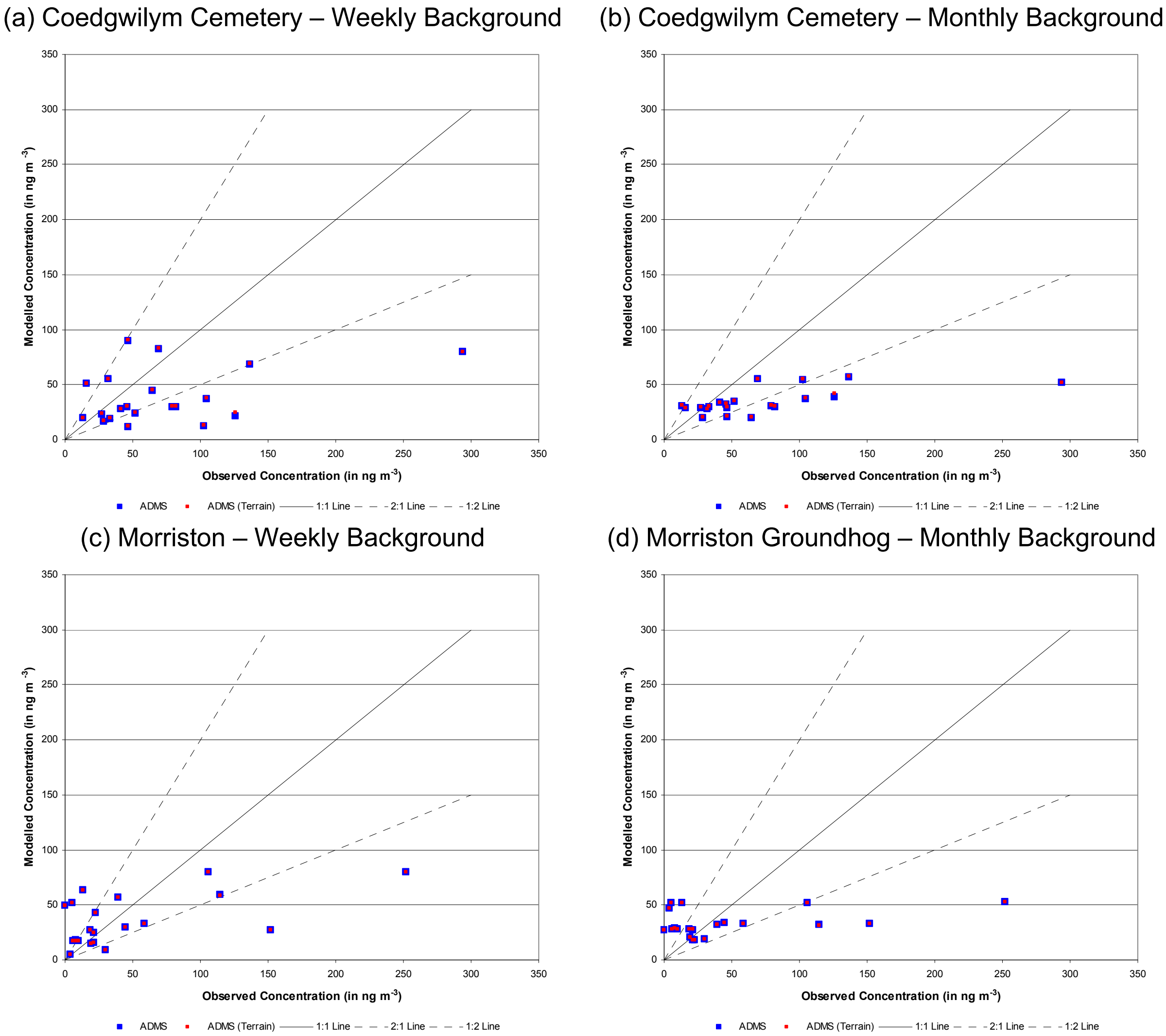

Figure 3-4: Scatter plots of the modelled and observed concentrations at Coedgwilym Cemetery (upper panels) and Morriston Groundhog (lower panels) using the measured weekly concentrations ('weekly background') or derived monthly-averaged concentrations ('monthly background').

It is conventional to consider the number of the modelled concentrations lying within a factor of 2 of the observed concentrations as a measure of the model performance or the accuracy of the input data. It can be seen from the 'weekly' scatter plots that most of the modelled concentrations lie within a factor of 2 of the observed concentrations, indicating an acceptable level of model performance.

3.4 Location of Sites

Figure 3-5 shows an expanded version of the contour map presented in Figure 3-2. The figure includes the locations of the source (red circle) and of the 4 monitoring sites (green squares). The monitoring sites, operated either as part of the Defra national monitoring programme or by the local council, are located as follows:

- INCO Europe (map ref: 270245,200475)
- Coedgwilym Cemetery (map ref: 270907,202100)
- YGG Gellionnen (map ref: 269240,201914)
- Morriston Groundhog (map ref: 267168,197593)

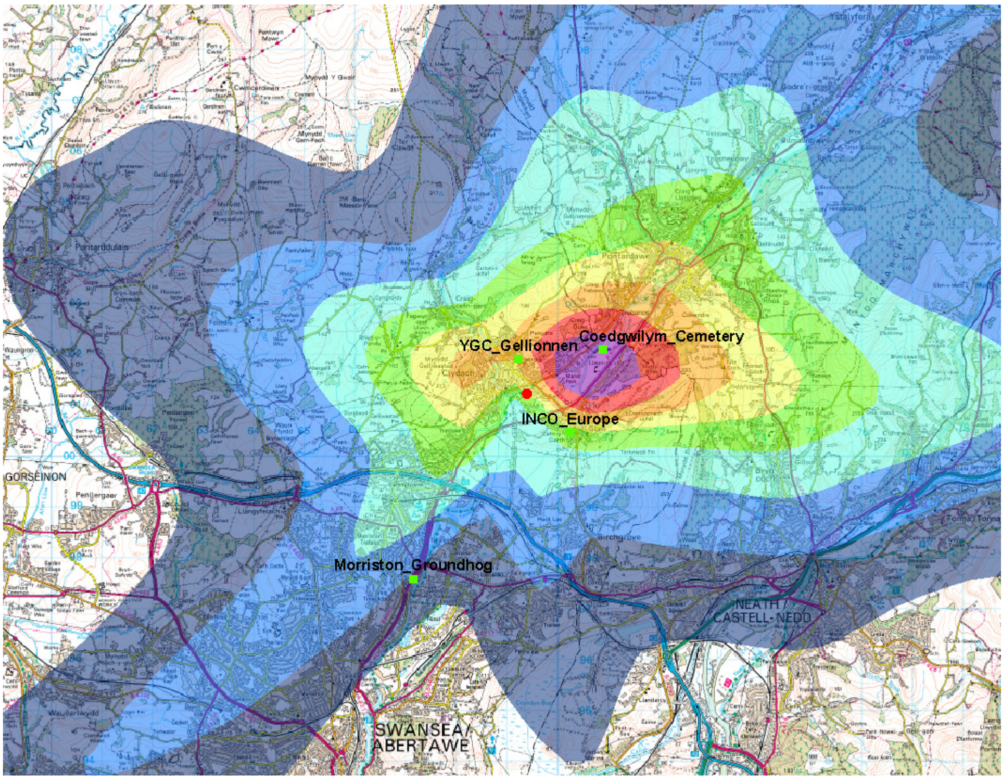

Figure 3-5: Expanded section of the modelled annual mean concentrations (in ng m^{-3}) for the model run using terrain data and Swansea 'weekly' background measurements.

The site at Coedgwilym Cemetery is situated in the area with the highest modelled nickel concentrations. The sites at INCO Europe and YGG Gellionnen are respectively to the south and west respectively of the highest concentration area. The Morriston Groundhog site is upwind from the area of highest concentrations.

Figure 3-5 presents the annual situation. Additional model runs were undertaken for specific Pasquil stability classes (see Table 2-2). Two wind directions (from 50° and 270°) were considered and default meteorological conditions were assumed for the stability classes. Figure 3-6 shows the resulting contour plots for stability classes B (unstable, upper panel) and D (neutral, lower panel). Both wind directions have been included in each plot. The model runs are for the source only (*i.e.*, no background measurements were added). A common colour scheme has been used.

The plume is more extensive under the unstable conditions and the three sites (Coedgwilym Cemetery, INCO Europe and YGG Gellionnen) all fall within the high concentration area for winds from the west. Only the Coedgwilym Cemetery site falls within the highest concentration area for the more frequent neutral conditions. The Morriston Groundhog site is upwind. For winds from the north east, the situation is reversed. The three sites (Coedgwilym Cemetery, INCO Europe and YGG Gellionnen) are upwind and it is the Morriston Groundhog site that has the highest modelled concentrations.

The sites therefore seem to be well located to assess the impact of the Vale INCO refinery.

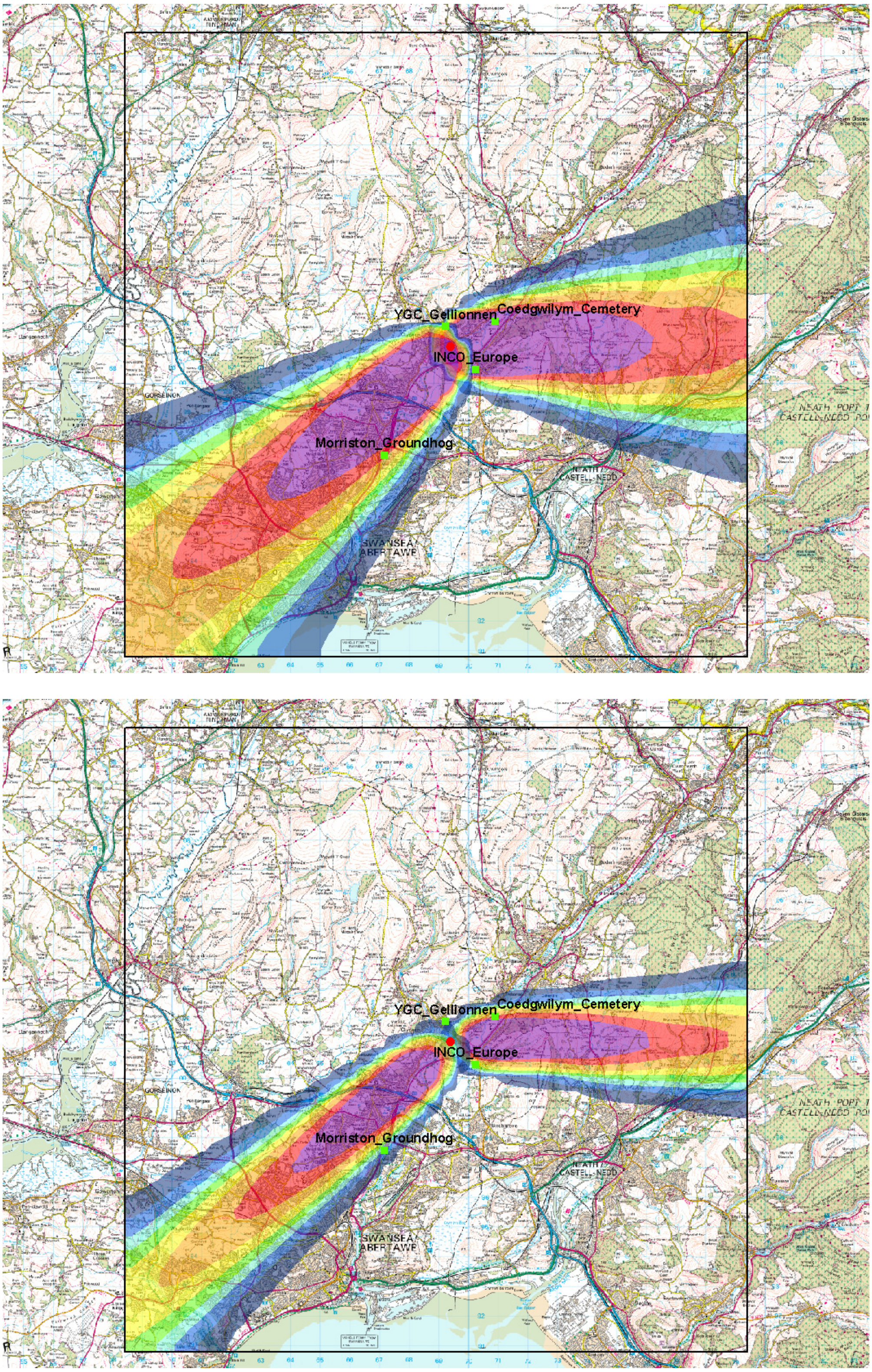

Figure 3-6: Contour maps of the modelled concentrations for Pasquil Stability Classes B (unstable, upper panel) and D (neutral, lower panel) with no background measurements. The concentrations in the purple area lie between 14.6 and 19.5 ng m^{-3}.

3.5 Additional Remarks

Modelled concentrations of metals in air tend to be underpredicted in many UK (e.g., see Vincent and Passant, 2006) and European (see for example the Review of the EMEP Models on Heavy Metals and Persistent Organic Compounds[7]) modelling studies, compared to observed ambient concentrations. This could arise if the reported emissions are too low, there are other emission sources (such as fugitive sources) present, or there are significant contributions from processes such as resuspension or volatilisation of particulate material from the surface, which have not been treated in the model.

Vincent and Passant (2006), in their national assessment modelling for the implementation of the 4th Daughter Directive, considered the significance of two additional sources of metals:

- **Fugitive Emissions**: These were to assumed to arise from metal processing plants and were considered to be area sources. Vincent and Passant assumed that the rate of these fugitive emissions was equivalent to three times the reported stack emissions
- **Resuspension**: A fraction of the coarse particulate matter was assumed to arise from the underlying soil and was entrained into the air through resuspension.

The study by Vincent and Passant concluded that the incorporation of fugitive emission did increase the modelled concentration near metal industry plants but, without confirmation of the emission rates, the method could only be seen as a sensitivity test. At Pontardawe (close to the refinery), the study reported that the concentrations of nickel in soil were significantly higher than the typical UK concentration range. However even assuming this local soil concentration, the contribution of soil to nickel concentrations was estimated to be ~2 ng m^{-3}.

Clearly, these could contribute and would increase the concentrations modelled in this work. Indeed, a further run undertaken in this work showed that the inclusion of a fugitive emission source - as an area source covering the refinery with an emission rate equivalent to 3 times the reported emissions – increased the maximum modelled concentration from ~8 ng m^{-3} to 55 ng m^{-3}. Further work is needed to confirm the existence and magnitude of such sources.

[7] See http://www.msceast.org/events/review.html

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Appendix 1

Observed Monthly Mean Nickel Concentrations (in ng m^{-3}) in 2006 at the Swansea and Cardiff Sites in the UK Heavy Metals Monitoring Network [taken from Brown *et al.*, 2007].

Site / Month	Swansea Ni Concentration (ng m^{-3})	Cardiff Ni Concentration (ng m^{-3})
January	30.86	5.35
February	15.76	5.60
March	24.35	2.40
April	26.86	4.54
May	18.68	4.79
June	20.04	3.28
July	18.98	3.15
August	27.42	4.78
September	18.19	2.09
October	32.60	3.06
November	27.72	4.00
December	52.09	2.13
Yearly Average	**26.13**	**3.76**

Appendix 2

Meteorological Conditions for different Pasquill Stability Classes

Surface Windspeed		Daytime Incoming Solar Radiation			Nighttime Cloud Cover	
m s^{-1}	miles hr^{-1}	strong	moderate	slight	> 50%	< 50%
<2	<5	A	A–B	B	E	F
2– 3	5–7	A–B	B	C	E	F
3–5	7–11	B	B–C	C	D	E
5–6	11–13	C	C–D	D	D	D
>6	>13	C	D	D	D	D

Appendix 3

Frequency of Different Dispersion Conditions

Pasquill Stability Analysis (A-G) - Frequency Table

Pasquill Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
A				5	11	12	13	4	2				**47**
A-B		2	44	94	127	141	149	114	70	10			**751**
B	58	75	117	182	238	249	248	208	161	64	73	60	**1733**
B-C	0	14	117	229	301	318	296	284	168	23			**1750**
C	410	531	718	820	841	997	897	801	603	473	508	397	**7996**
C-D		21	92	175	235	270	200	234	146	29			**1402**
D	5102	4711	4829	4730	4586	3803	4036	3919	4456	5328	4848	5338	**55686**
E	411	391	407	431	354	351	343	528	434	419	557	483	**5109**
F	149	164	220	237	191	249	200	213	193	123	208	181	**2328**
G	13	12	15	12	23	19	17	27	10	11	8	21	**188**
Total	**6143**	**5921**	**6559**	**6915**	**6907**	**6409**	**6399**	**6332**	**6243**	**6480**	**6202**	**6480**	**76990**

Pasquill Stability Analysis (A-G) - Percentage Table

Pasquill Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
A				0.1	0.2	0.2	0.2	0.1	0.0				**0.1**
A-B			0.7	1.4	1.8	2.2	2.3	1.8	1.1	0.2			**1.0**
B	0.9	1.3	1.8	2.6	3.4	3.9	3.9	3.3	2.6	1.0	1.2	0.9	**2.3**
B-C		0.2	1.8	3.3	4.4	5.0	4.6	4.5	2.7	0.4			**2.3**
C	6.7	9.0	10.9	11.9	12.2	15.6	14.0	12.7	9.7	7.3	8.2	6.1	**10.4**
C-D		0.4	1.4	2.5	3.4	4.2	3.1	3.7	2.3	0.4	0.0	0.0	**1.8**
D	83.1	79.6	73.6	68.4	66.4	59.3	63.1	61.9	71.4	82.2	78.2	82.4	**72.3**
E	6.7	6.6	6.2	6.2	5.1	5.5	5.4	8.3	7.0	6.5	9.0	7.5	**6.6**
F	2.4	2.8	3.4	3.4	2.8	3.9	3.1	3.4	3.1	1.9	3.4	2.8	**3.0**
G	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.2	0.2	0.1	0.3	**0.2**

Appendix 4

Measured Nickel Concentrations at the Coedgwilym Cemetery and Morriston Groundhog Monitoring Sites

Coedgwilym Cemetery			
Filter Number	Start Date	End Date	Concentration (ng m^{-3})
100/2311	26/07/2006	02/08/2006	27.36
100/2312	02/08/2006	09/08/2006	13.52
100/2313	09/08/2006	16/08/2006	15.68
100/2314	16/08/2006	23/08/2006	46.14
100/2412	23/08/2006	30/08/2006	46.5
100/2413	30/08/2006	06/09/2006	126.1
100/2414	06/09/2006	13/09/2006	46.5
100/2415	13/09/2006	20/09/2006	64.6
100/2514	20/09/2006	27/09/2006	28.5
100/2515	27/09/2006	04/10/2006	82.0
100/2516	04/10/2006	11/10/2006	104.9
100/2517	11/10/2006	18/10/2006	41.3
100/2616	*not exposed*		-
100/2617	01/11/2006	01/11/2006	-
100/2618	01/11/2006	06/11/2006	32.1
100/2619	08/11/2006	15/11/2006	33.3
100/2620	15/11/2006	22/11/2006	79.1
100/2621	22/11/2006	29/11/2006	52.1
100/2622	29/11/2006	06/12/2006	102
100/2623	06/12/2006	13/12/2006	136
100/2624	13/12/2006	20/12/2006	69.3
100/2625	21/12/2006	23/12/2006	294.2
100/2626	28/12/2006	03/01/2007	97.2
100/2627	03/01/2007	10/01/2007	53.9

Morriston Groundhog			
Filter Number	Start Date	End Date	Concentration (ng m^{-3})
101/2378	26/07/2006	02/08/2006	19.47
101/2379	02/08/2006	09/08/2006	8.29
101/2380	09/08/2006	16/08/2006	0.03
101/2381	16/08/2006	23/08/2006	21.56
101/2480	*not exposed*		-
101/2481	06/09/2006	06/09/2006	-
101/2482	06/09/2006	13/09/2006	29.7
101/2483	13/09/2006	20/09/2006	22.6
101/2582	20/09/2006	27/09/2006	21.1
101/2583	04/10/2006	04/10/2006	-
101/2584	04/10/2006	11/10/2006	58.8
101/2585	11/10/2006	16/10/2006	151.7
101/2683	18/10/2006	25/10/2006	44.8
101/2684	25/10/2006	01/11/2006	39.2
101/2685	01/11/2006	05/11/2006	114.6
101/2686	08/11/2006	15/11/2006	10.1
101/2687	15/11/2006	22/11/2006	18.8
101/2688	22/11/2006	29/11/2006	5.8
101/2689	29/11/2006	06/12/2006	3.9
101/2690	06/12/2006	13/12/2006	13.5
101/2691	13/12/2006	20/12/2006	106.0
101/2692	20/12/2006	22/12/2006	251.7
101/2693	28/12/2006	03/01/2007	5.4
101/2694	03/01/2007	10/01/2007	12.3