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CALCULATIONS OF ANNUAL AVERAGE SO_2 CONCENTRATIONS AND SULPHUR DEPOSITION AT DISTANCES UP TO 100 KM FROM MOUNT ISA

Report to Mount Isa Mines Limited

by

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SUMMARY

Calculations of the annual average concentration of SO_2 from the Mount Isa copper and lead smelters have been carried out for distances up to 100 km from Mount Isa.

A gaussian plume model was used in conjunction with 4 years of hourly wind data from the Mount Isa Mines Limited elevated anemometer. Calculations were carried out on an hourly basis for each of 12 month periods for the years 1986/87, 1987/88, 1988/89 and 1990/91.

Two emission cases were used, one corresponding to a base case with a total SO_2 emission rate of 25.3 kg s^{-1} and the other an expanded case (300 k tonne case) with a total SO_2 emission rate of 39.6 kg s^{-1}. Contours of annual average SO_2 concentrations were produced on the assumption that plume touchdown only occurred between 800 to 1800 hrs in winter and 700 to 1900 hours in summer. The Mount Isa Mines Limited air quality control shut down procedures during westerly winds were explicitly taken into account in the calculations.

The calculations show that the 5 $\mu g\ m^{-3}$ annual average SO_2 contour extends from ~ 90 km to ~ 110 km to the west and north west of Mount Isa for each of the 4 years of wind data considered and for the base case emissions. Also for the years 1987/88, 1988/89 and 1990/91 the 5 $\mu g\ m^{-3}$ contour extends in a finger like projection ~ 130 km to the south west. For the 300 k tonne case the 5 μgm^{-3} contour of SO_2 concentration extend out to > 100 km from the smelters.

Calculations of the dry deposition of SO_2 show values of 5 kg ha^{-1} yr^{-1} (~8mmole m^{-2} yr^{-1}) at distances up to 75 km west or northwest of the sources for the base case emissions. The 300 k tonne emissions increase this distance to > 100 km. For the base case emissions the 150 kg $ha^{-1}yr^{-1}$ isopleth occurs at a distance of ~ 9 km from the sources, for the 300 k tonne emissions this distance increases to about 12 km.

Estimates of the wet deposition show that rainfall in the vicinity of the plume and within ~ 20 km of the source would result in between ~ 3 to ~ 5 mmole m^{-2} (2 to 3.3 kg ha^{-1} as SO_2 equivalent) for a wet deposition of sulphur from an average rain event of rainfall 8.5 mm for the base case and 300 k tonne emissions respectively. However at the time of writing the frequency of occurrence of rain events with respect to plume location is not clear. Further work is required in this area before conclusions can be drawn.

Because of the number and complexity of the processes involved it is clear that the results of the calculations presented in this report can only serve as an approximate guide to potential sulphur deposition. If the modelled deposition rates, taking into account the uncertainties involved, give any reason for concern then the only method of confirming the estimates is by a program of direct measurement, particularly in any area which might be considered sensitive to sulphur deposition.

1. INTRODUCTION

SO_2 is emitted into the atmosphere as a result of the copper and lead smelting operations carried out by Mount Isa Mines Limited at Mount Isa.

This report presents calculations of the annual average concentrations of SO_2 from the Mount Isa copper and lead smelters. The model predictions have been used to estimate the wet and dry deposition of sulphur up to distances of ~100 km from Mount Isa.

2. METHODOLOGY

2.1 Gaussian plume model

The ground level concentrations of SO_2 were calculated from a gaussian plume model used previously at Mount Isa (see Carras and Williams, 1992).

The major assumptions of the gaussian model have been described in detail by Carras and Williams (1992) and will not be reproduced here. Two further assumptions used in the present calculation were as follows:

i) The plumes were considered to reach the ground only during convective conditions which were defined to occur during the hours of 800 to 1800 during the winter months and 700 to 1900 during summer.

ii) The mixing height in all the calculations was taken to be constant independent of the time of day and to have a value of 2000 m.

2.2 Emissions data

Emissions data for use in the calculations were provided by MIM and these are shown in Table 1. The base case as well as the 300 k tonne case were used to carry out two complete sets of calculations of annual average ground level concentrations (glc) of SO_2.

2.3 Wind data

U62 wind speed and direction data were provided by Mount Isa Mines Limited as 5 minute averages. The 5 minute averages were used to create 1 hour averages of wind speed and direction for each hour of the 4 year period 1986/87 to 1988/89 and 1990/91.

The annual distribution of wind speed and direction were also calculated from the U62 wind data for each year for daytime convective conditions and for the combined 4 year period. For this purpose the wind direction data were binned into 10° intervals and the fraction of each year the wind was in each direction calculated. The results of these calculations are shown in Tables 2 and 3 for each of the four year periods considered in this work. Also shown (Table 4) are the wind statistics averaged over the entire 4 year period.

2.4 Air quality control shut-down procedures

In order to maintain acceptable air quality in the Mount Isa town and suburbs Mount Isa Mines operate a smelter shut-down procedure when adverse wind directions and speeds occur.

For the purposes of the current calculation the shut-down procedures were modelled as follows:

i) For all westerly wind directions the copper smelter emissions were assumed to be reduced to the equivalent of 1 converter or the FSR (see Table 1).

ii) For all westerly wind directions and wind speeds less than or equal to 2 ms^{-1} the lead and copper smelter emissions were assumed to be zero, i.e. total shut-down of both smelters occurred.

2.5 Calculation of annual average glc of SO_2

The region surrounding Mount Isa was divided into a grid extending 100 km in all directions from Mount Isa. The grid spacing used was 2km. The gaussian plume model was used in conjunction with the hourly average wind data to create contours of glc of SO_2 for each 12 month period and each set of emissions conditions. This was done as follows:

i) The hourly average glc of SO_2 for each grid point was calculated for a given wind direction and wind speed for each hour during daytime conditions as defined above. The value of the horizontal dispersion coefficient, σ_y, used in the calculations was 1.4 times the 15 min value used in calculating SO_2 glc in previous reports (see e.g. Carras and Williams 1992). This follows the recommendation of Gifford (1975) whereby

$$\sigma_y(t_1)/\sigma_y(t_2) = (t_2/t_1)^{0.25}$$

for averaging times t_1 and t_2.

ii) The resulting values of glc SO_2 at each grid point were averaged over the entire year. In reporting the maximum glc, it should be noted that the "real" maximum value may in fact occur between the grid points.

iii) In calculating SO_2 glc the air quality control shut down procedures were included explicitly in the model calculations, i.e. when a westerly wind prevailed the copper emissions were reduced to either 1 converter or the FSR (see Table 1), also if the wind speed during a westerly wind situation was less than or equal to 2 ms^{-1} it was assumed that all SO_2 emissions from the copper and lead smelters ceased.

3. RESULTS AND DISCUSSION

3.1 Annual average glc of SO_2

The modelling procedure outlined above was run for each set of emission conditions and for each of the 4 sets of annual wind data and for the combined four year wind data.

Figure 1 shows the calculated annual average SO_2 glc for the 1986/87 wind data and the base case emissions. The isopleths of SO_2 are seen to mirror the wind data (see Table 2) except for the fact that the plume impact in the eastern half plane is severely constrained due to the smelter shut down procedure. Contours with values of SO_2 concentration of 5, 10, 20, 50, 100, 200 and 500 $\mu g\ m^{-3}$ are shown.

Indeed instead of the 1 hour data the annual wind statistics can be used to calculate the isopleths. This has been done and the results show good agreement with those using the 1 hour data. However the maximum glc are badly underestimated as these are caused largely by low wind speed conditions which are not fully reflected by the use of annual average wind speeds.

Figure 1 shows that the 5 $\mu g\ m^{-3}$ isopleth extends ~ 90 km to the west of Mount Isa while the 10 $\mu g\ m^{-3}$ isopleth extends ~55 km from Mount Isa toward the west. The pattern is extended in the NW quadrant indicating the prevalence of SE winds during 1986/87. The maximum annual average hourly glc of SO_2 predicted on the grid used is 1217 $\mu g\ m^{-3}$ and this occurs within ~2 km of the smelters.

Figures 2 to 4 show similar calculations for the base case emissions and for the years 1987/88, 1988/89 and 1990/91. While these patterns are similar in extent to the pattern for 1986/87, there is a 'finger' of SO_2 extending toward the south west. Inspection of the wind data in Tables 2 and 3 confirms a greater frequency of NE winds in these 3 years than for the 1986/87 year.

Maximum annual average hourly concentrations for the grid used are 1364, 1062 and 1058 $\mu g\ m^{-3}$ for the years 1987/88, 1988/89 and 1990/91, respectively.

Figures 5 to 8 show the corresponding results for the emissions from the 300 k tonne smelter scenario. The increased emissions resulted in calculated maximum annual average hourly concentrations of 1990, 2048, 2457 and 1734 $\mu g\ m^{-3}$ for the years 1986/87, 1987/88, 1988/89 and 1990/91 respectively.

A comparison of Figures 1 to 4 with the corresponding Figures 5 to 8 shows the increased emissions extend the area and increase the general SO_2 background in the region modelled. For instance a comparison of Figure 1 and Figure 5 shows that the increased emission extends the 5 $\mu g\ m^{-3}$ contour of SO_2 out to a distance ~130 km to the west and north west of Mount Isa while the 10 $\mu g\ m^{-3}$ isopleth extends out to ~ 75 km to the west of the smelters.

Figure 9 shows the calculated annual average glc for the base case emissions and using the 1 hourly wind data for the four year period. Again the pattern reflects the wind data (Table 4), the maximum average value for the grid spacing used being 1160 $\mu g\ m^{-3}$.

Figure 10 show the results of the corresponding calculation appropriate to the 300 k tonne case. Again the pattern reflects the wind data and the maximum average glc has risen to 2014 $\mu g\ m^{-3}$.

3.2 Dry Deposition of SO_2

The deposition of SO_2 to arid regions in Australia has been measured by Milne et al (1979) and Williams et al (1981). These workers covered small trees, plants and grasses as well as bare soil with a teflon chamber and measured the decay of SO_2 injected into the chamber as a function of time. From the SO_2 decay and assuming a first order process the dry deposition velocity of SO_2 was measured. These authors found that the dry deposition velocity varied typically from ~ 0.1 cm s^{-1} for the region surrounding Mount Isa in winter time, when the area was under severe water stress, to ~ 0.4 cm s^{-1} near Tennant Creek after recent rain.

In the current work we have taken a value of 0.3 cm s^{-1} to be representative of a mix of dry and wet conditions for the region for which the calculations were performed.

The flux of SO_2 deposited to the surface is assumed to be proportional to the SO_2 concentration i.e.

$$J = v\chi$$

where J is the surface flux, χ the concentration of SO_2 and v the constant of proportionality known as the deposition velocity.

Table 5 shows some values of the total SO_2 deposited in one year assuming a deposition velocity of 0.3 cm s^{-1} for various values of annual average SO_2 concentrations. An annual average SO_2 concentration of 1 $\mu g\ m^{-3}$ results in dry deposition of ~ 1 kg ha^{-1} or 1.5 mmole m^{-2}. As the surface flux is simply proportional to the concentration the mass deposited increases in proportion to concentration increase. Note in all the dry deposition calculations described in this report no attempt has been made to allow for the reducing flux of SO_2 due to the removal processes described. This amounts to about 5% per day for dry deposition plus a similar amount for photo-oxidation. For distances of 100 km from Mount Isa the loss has little significance for the current estimates.

The results of the calculations described above allow estimates of the deposition of SO_2 expected in the vicinity of Mount Isa. Figure 11 shows isopleths of annual dry deposition predicted from the gaussian plume model for the region surrounding Mount Isa. The calculations are for the base case emissions and for data averaged over the 4 year period. The outer isopleth shown corresponds to an annual deposition rate of 5 kg ha^{-1} (~ 8 mmole m^{-2}) and extends ~ 75 km in the western area from Mount Isa. The 10 kg ha^{-1} (~16 mmole m^{-2}) extends ~ 48 km in the western area from Mount Isa with the 150 kg

ha^{-1} value (~ 234 mmole m^{-2}) within ~ 9 km of the smelters. Clearly, close to the sources the model predicts significant dry deposition of SO_2.

Figure 12 shows the predictions of annual dry deposition of SO_2 for the 300 k tonne production scenario for the same four year period. The values are larger, mirroring the increased ground level concentrations due to the increased emissions. The 5 kg ha^{-1} (8 mmole m^{-2}) isopleth extends at least 100 km to the west of Mount Isa for the data in Figure 12. The 10 kg ha^{-1} (-16 mmole m^{-2}) extends ~ 70 km in the western area from Mount Isa while the 150 kg ha^{-1} value extends a distance of ~12 km and covers a larger area than for the base case.

3.3 Wet deposition of sulphur

Estimating the wet deposition of sulphur is significantly more difficult than estimating dry deposition.

Pena et al (1982) have presented data to support the hypothesis that the sulphur content in rainwater is given by the equilibrium values corresponding to the surface SO_2 concentration in air and the aqueous concentration of HSO_3^-. Figure 13 shows the results of calculating the $[HSO_3^-]$ in rainwater as a function of ambient temperature and ambient SO_2 concentration assuming rainwater of pH=5 due solely to the presence of HSO_3^-. In reality, the presence of HCO_3^- and organic acids will further influence rainwater pH and the $[HSO_3^-]$. (The square brackets denote concentration). The calculations are based on the equation

$$[HSO^-_3] = K_h K_1 [SO_2]/[H^+]$$

where $\text{Log } K_h = 1373.9/T - 4.159$

$\text{Log } K_1 = 868.3/T - 4.805$

and T is in degrees Kelvin

The values of $[HSO_3^-]$ in rainwater in Figure 13 can be used in conjunction with SO_2 concentration calculations as well as rainfall information to estimate likely wet deposition. As most of the rain falls in the summer period, the likely rain temperature will be in the range 20-30°C.

Table 6 shows a summary of the ten year rainfall data from 1982 to 1991 at Mount Isa. The total rainfall as well as the number of raindays/year is shown. Also shown is the ten year average annual rainfall, average rain days/year and the average rainfall/rain day.

Table 7 shows calculations of the 'instantaneous' SO_2 concentration in the combined Mount Isa plume for the base case emissions as well as the 300 k tonne emissions. The calculations were carried out using a simple box model, a wind speed of 5 ms^{-1}, a mixing height of 2000 m, four values of downwind distance and assuming the combined SO_2 was emitted from a single stack. The equilibrium concentrations of $[HSO_3^-]$ in rainwater at 25°C and based on the above considerations are also shown. On the assumption that an average rain event results in 8.5 mm of rain the wet deposition of HSO_3^-/event was also calculated and is shown in Table 7.

The wet deposition/rain event for the base case ranges from ~6 mmole m^{-2} at 10 km from the source to <1 mmole m^{-2} at 100 km. For the 300 k tonne case these values increase to ~10 mmole m^{-2} and 1 mmole m^{-2} at 10 km and 100 km respectively. (Note that rainfall of significantly lower ambient temperature, e.g. 15°C would increase the $[HSO_3^-]$ and hence deposition values by a factor of 2 to 3).

In order to estimate the likely wet deposition for 100 km around Mount Isa, and in view of the convective nature of the rain showers, much greater detail on rainfall within the surrounding area would be required along with a detailed analysis of wind direction and rain events. Nevertheless the assumption of say five rain events per year at a particular site would indicate wet deposition of between ~30 to 50 mmole m^{-2} yr^{-1} at 10 km from the source and 3 to 5 mmole m^{-2} yr^{-1} at 100 km from the source.

3.4 Reliability of the calculations

The results presented in this work are based on a number of assumptions. These need to be stated so that the reliability of the results may be appreciated.

First the assumptions associated with the gaussian plume modelling have been stated by Carras and Williams (1992). Notwithstanding these assumptions Hayes and Moore (1986) have shown that when the requirement of spatial and temporal resolution are relaxed the prediction of gaussian models are within approximately a factor of 2 of the maximum glc's recorded at a particular location. However, improvements in model paramaterization have greatly improved the ability of gaussian models to predict short term glc in the vicinity of a given location. Also, the short term turbulent fluctuations which produce an inherent variability in short term glc become unimportant when calculating annual averages.

The uncertainty in the dry deposition estimates depend on the uncertainty in the deposition velocity as well as the SO_2 concentration. However, over a long averaging period such as a year the uncertainty is likely to be similar as for SO_2 glc.

The uncertainties in the wet deposition estimates are more difficult to quantify, and are greater than for the SO_2 and the dry deposition estimates.

It is clear that the results of the calculations presented in this report can only serve as an approximate guide to potential sulphur deposition. The only method of confirming these estimates is by a monitoring program of direct measurement, particularly in areas which might be considered sensitive to sulphur deposition.

4. CONCLUSION

Calculations of the annual average hourly concentration of SO_2 have been carried out for distances up to 100 km from Mount Isa. Two emissions cases were used, one corresponding to a base case with a total SO_2 emission rate of 25.3 kg s^{-1} and the other an expanded case with a total SO_2 emission rate of 39.6 kg s^{-1}.

The calculations show that the 5 $\mu g\ m^{-3}$ annual average SO_2 contour extends from ~ 90 to ~ 110 km to the west and north west of Mount Isa for each of the 4 years of wind data considered and for the base case emission. Also for the years 1987/88, 1988/89 and 1990/91 the 5 $\mu g\ m^{-3}$ contour extends in a finger like projection ~ 130 km to the south west. For the 300 k tonne case the 5 $\mu g\ m^{-3}$ contour of SO_2 concentrations extend out to > 100 km from the smelters.

Calculations of the dry deposition of SO_2 show values of 5 kg ha^{-1} yr^{-1} (~ 8 mmole m^{-2} yr^{-1}) at distances up to 75 km west or northwest of the sources for the base case emissions. The 300 k tonne emissions increase this distance to > 100 km. For the base case emissions the 150 kg ha^{-1} yr^{-1} isopleth ocurs at a distance of ~ 9 km from the sources, for the 300 k tonne emissions thus distance increases to about 12 km.

Estimates of the wet deposition show that rainfall in the vicinity of the plume and within ~ 20 km of the source would result in between ~ 3 to ~ 5 mmole m^{-2} (ie 2 to 3.3 kg ha^{-1} as SO_2 equivalent) for a wet deposition of sulphur from an average rain event of rainfall 8.5 mm for the base case and 300k tonne emissions, respectively. However at the time of writing the frequency of occurrence of rain events with respect to plume location is not clear. Further work is required in this area before conclusions can be drawn.

Because of the number and complexity of the processes involved it is clear that the results of the calculations presented in this report can only serve as an approximate guide to potential sulphur deposition. If the modelled deposition rates, taking into account the uncertainties involved, give any reason for concern then the only method of confirming the estimates is by a program of direct measurement, particularly in any area which might be considered sensitive to sulphur deposition.

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Table 1 Emission values used in the calculations

	Flow rate ($Nm^3 s^{-1}$)	Temp. (C)	Stack Ht. (m)	SO_2 ($kg s^{-1}$)	SO_2%
			Base Case		
Pb	245	89	273	6.7	0.95
Cu	265	225	153	18.6	2.45
			300 k tonne		
Pb	264	95	273	8.3	1.10
Cu	359	185	153	31.3	3.06
			Westerly Wind		
Cu	75	220	153	4.5	
Pb	as above				

Table 2 Wind statistics for the 2 years 1986/87 and 1987/88. The data are limited to the period 0800 to 1800 hours during winter and 0700 to 1900 hours during summer.

Wind Direction		1986/87 Wind Speed (ms^{-1})	Frequency (%)	1987/88 Windspeed (ms^{-1})	Frequency (%)
0	9	5.7	0.4	8.6	0.4
10	19	6.7	1.2	4.5	0.4
20	29	5.6	2.6	5.4	1.6
30	39	5.2	2.8	5.4	3.2
40	49	5.0	3.2	5.8	9.6
50	59	5.1	4.4	5.5	6.0
60	69	4.4	3.8	5.1	4.2
70	79	4.5	4.6	5.3	4.2
80	89	4.6	5.6	5.2	5.8
90	99	4.8	6.6	5.7	6.8
100	109	5.2	5.6	5.9	8.0
110	119	5.5	7.2	5.9	6.8
120	129	6.0	7.6	6.2	6.8
130	139	6.1	8.2	6.6	7.2
140	149	6.1	6.6	6.1	3.6
150	159	5.9	4.4	5.3	2.8
160	169	5.4	3.6	2.7	2.8
170	179	5.2	2.0	5.6	1.4
180	189	4.6	1.6	5.0	1.6
190	199	4.1	1.4	5.4	2.0
200	209	3.7	1.4	5.1	1.2
210	219	4.4	1.6	4.3	1.0
220	229	4.0	1.4	5.0	1.0
230	239	4.7	1.4	5.1	1.0
240	249	4.9	1.4	4.8	1.0
250	259	4.2	1.4	5.3	1.0
260	269	4.1	1.0	6.0	1.0
270	279	4.6	0.8	6.1	1.0
280	289	4.7	1.4	6.1	1.6
290	299	4.3	1.0	4.9	1.0
300	309	5.7	1.0	5.1	1.2
310	319	5.5	1.0	5.4	0.4
320	329	4.9	0.8	6.7	0.6
330	339	6.5	0.3	5.9	0.4
340	349	6.2	0.4	5.9	0.4
350	359	-	-	-	-

Table 3 Wind statistics for the 2 years 1988/89 and 1990/91. The data are limited to the period 0800 to 1800 hours during winter and 0700 to 1900 hours during summer.

Wind Direction		1988/90 Wind Speed (ms^{-1})	Frequency (%)	1990/91 Windspeed (ms^{-1})	Frequency (%)
0	9	6.7	0.2	3.9	0.1
10	19	6.6	1.0	4.3	0.8
20	29	6.0	2.0	4.5	2.4
30	39	5.8	4.6	5.2	9.2
40	49	5.6	10.2	4.9	4.4
50	59	5.2	6.2	4.6	4.4
60	69	5.0	4.2	4.6	3.6
70	79	4.7	4.0	5.1	3.7
80	89	5.1	4.6	5.1	3.6
90	99	5.5	5.4	5.4	5.0
100	109	6.1	5.4	5.5	5.8
110	119	6.1	7.6	5.5	6.6
120	129	6.4	7.2	5.9	7.8
130	139	6.5	7.4	5.7	6.8
140	149	6.1	6.2	6.1	7.0
150	159	6.2	3.8	6.7	6.8
160	169	6.0	3.2	6.7	5.0
170	179	5.5	2.4	5.8	2.2
180	189	5.1	1.6	4.7	1.0
190	199	5.7	1.6	4.4	1.2
200	209	7.8	2.4	3.9	0.8
210	219	4.7	0.8	4.5	0.6
220	229	4.4	1.6	3.3	1.2
230	239	4.8	0.8	3.9	0.8
240	249	4.3	0.8	3.6	1.0
250	259	5.4	1.0	2.7	1.2
260	269	4.7	0.8	4.0	0.8
270	279	5.6	0.4	4.0	0.6
280	289	4.7	0.6	4.2	1.0
290	299	4.6	0.6	4.5	1.0
300	309	5.7	0.4	4.4	0.8
310	319	4.5	0.4	4.6	0.8
320	329	4.2	0.2	3.9	0.6
330	339	5.7	0.2	3.7	0.6
340	349	7.6	0	3.4	0.2
350	356	-	-	3.4	0.0

Table 4 Wind statistics for the four year data, i.e. 1986/87, 1987/88, 1988/89 and 1990/91 combined. The data are limited to the period 0800 to 1800 hours during winter and 0700 to 1900 hours during summer.

Wind Direction		Windspeed (ms^{-1})	Frequency (%)
0	9	6.9	0.2
10	19	5.8	0.8
20	29	5.3	2.2
30	39	5.4	5.0
40	49	5.5	6.8
50	59	5.1	5.2
60	69	4.8	4.0
70	79	4.9	4.2
80	89	5.0	4.8
90	99	5.3	6.0
100	109	5.7	6.2
110	119	5.8	7.0
120	129	6.1	7.4
130	139	6.2	7.4
140	149	5.4	5.8
150	159	5.5	4.4
160	169	4.9	3.6
170	179	5.0	2.0
180	189	5.7	1.4
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270	279	5.1	0.8
280	289	5.1	1.2
290	299	4.6	0.8
300	309	4.2	0.8
310	319	5.1	0.6
320	329	5.0	0.6
330	339	5.4	0.4
340	349	5.7	0.2
350	359	3.4	0.0

Table 5 Total mass per unit area of SO_2 deposited to the ground per year for various values of SO_2 concentration and for a deposition velocity of 0.3 cm s^{-1}

C ($\mu g\ m^{-3}$)	D ($kg\ ha^{-1}$)	D ($mmole\ m^{-2}$)
1	0.95	1.5
10	9.5	15
100	95	148

C is concentration of SO_2
D is deposition of SO_2

Table 6 Annual average rainfall statistics for Mount Isa (data provided by Mount Isa Mines)

Year	Total Rain (mm)	Number of Rain Days
1982	338	48
1983	548	58
1984	615	49
1985	239	38
1986	266	41
1987	347	52
1988	258	28
1989	299	42
1990	273	34
1991	590	52

Ten year average annual rainfall = 377 mm
Ten year average annual raindays = 44 days/year
Ten year average rain/rain day = 8.5 mm

Table 7 Estimates of the amount of wet deposition in 8.5 mm of rain assuming the plume is in the rain at an ambient temperature of 25°C

Base Case				300 k tonne case			
X (km)	C ($\mu g\ m^{-3}$)	$[HSO_3^-]$ ($\mu M/L$)	D* ($mM\ m^{-2}$)	X (km)	C ($\mu g\ m^{3}$)	$[HSO_3^-]$ ($\mu M\ L^{-1}$)	D* ($mM\ m^{-2}$)
10	516	720	6.1	10	808	1128	9.6
20	258	360	3.1	20	404	564	4.8
50	103	145	1.2	50	162	226	1.9
100	52	73	0.6	100	81	113	1.0

*Wet deposition resulting from 8.5 mm rainfall
C - concentration of SO_2 in air
D - deposition

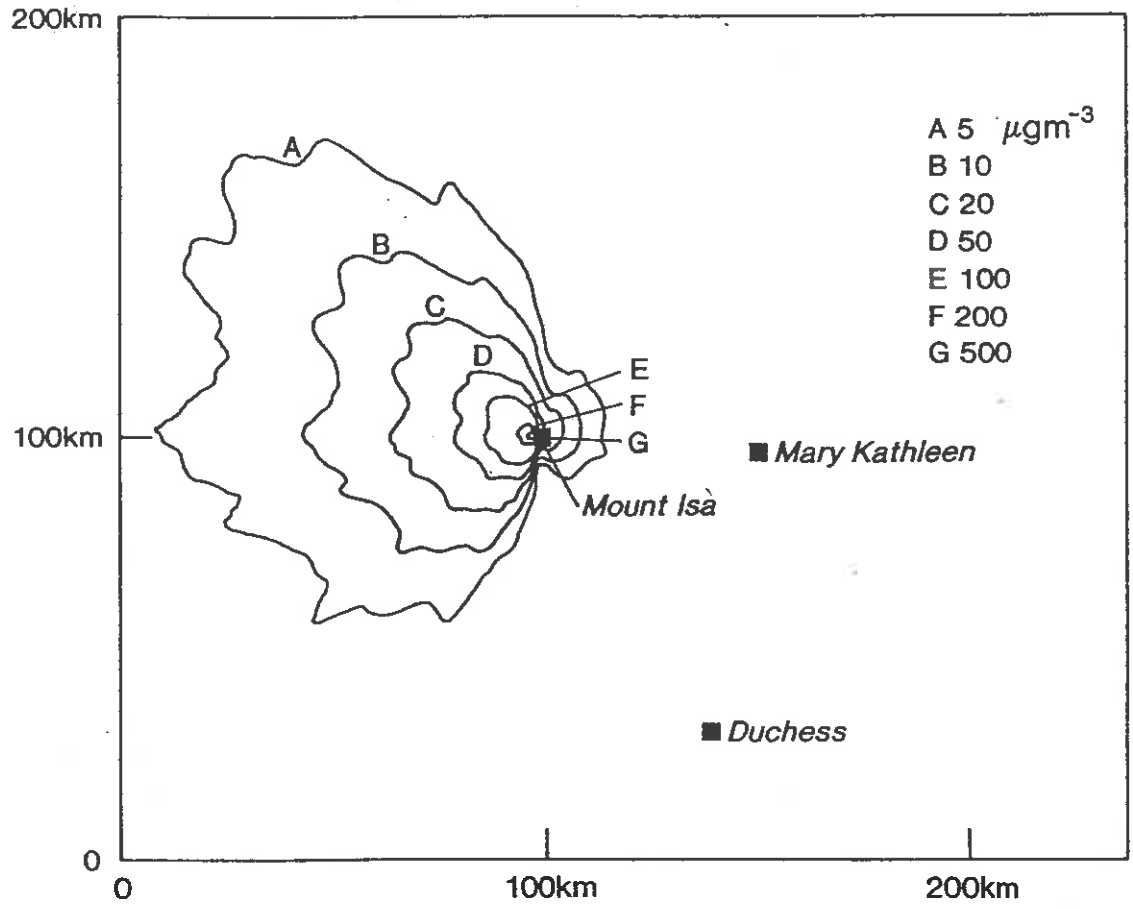

Figure 1 Isopleths of annual average ground level concentration of SO_2 for the year 1986/87 assuming base case emissions.

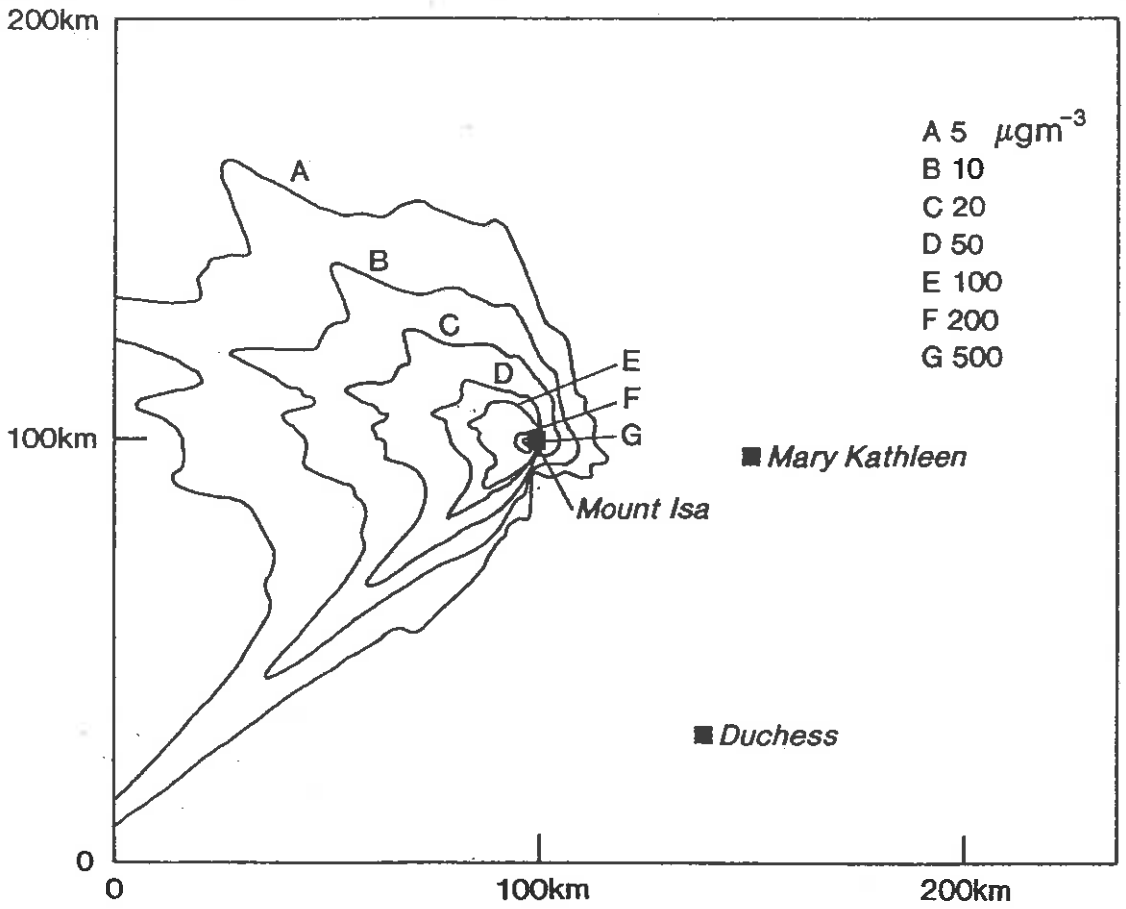

Figure 2 Isopleths of annual average ground level concentration of SO_2 for the year 1987/88 assuming base case emissions.

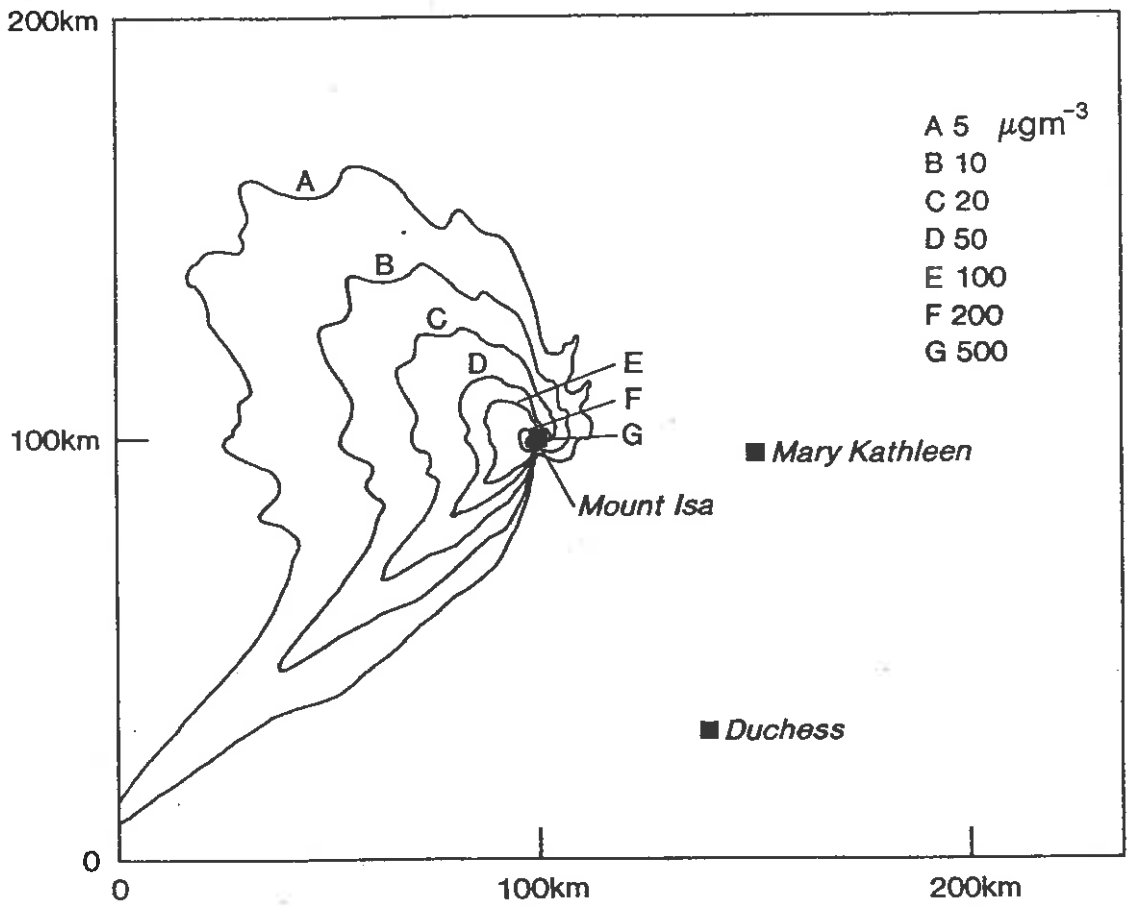

Figure 3 Isopleths of annual average ground level concentration of SO_2 for the year 1988/89 assuming base case emissions.

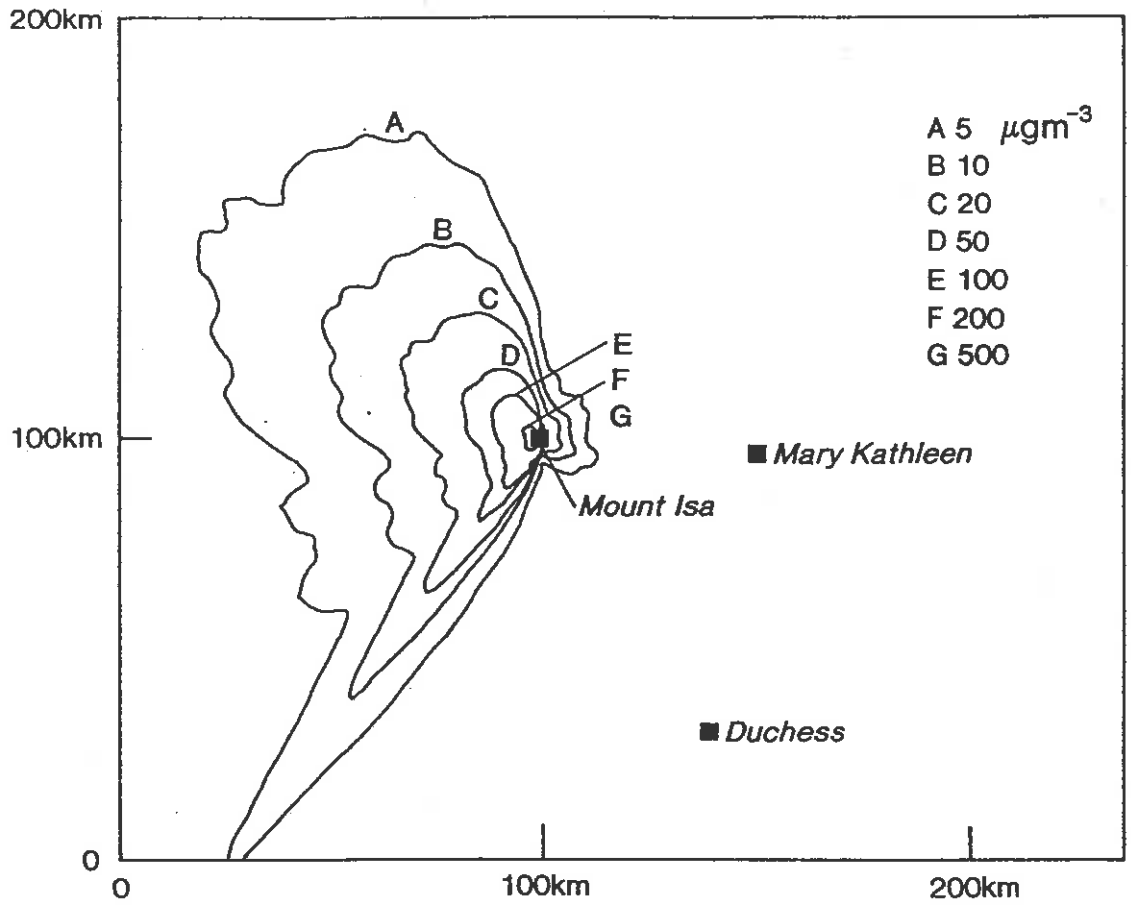

Figure 4 Isopleths of annual average ground level concentration of SO_2 for the year 1990/91 assuming base case emissions.

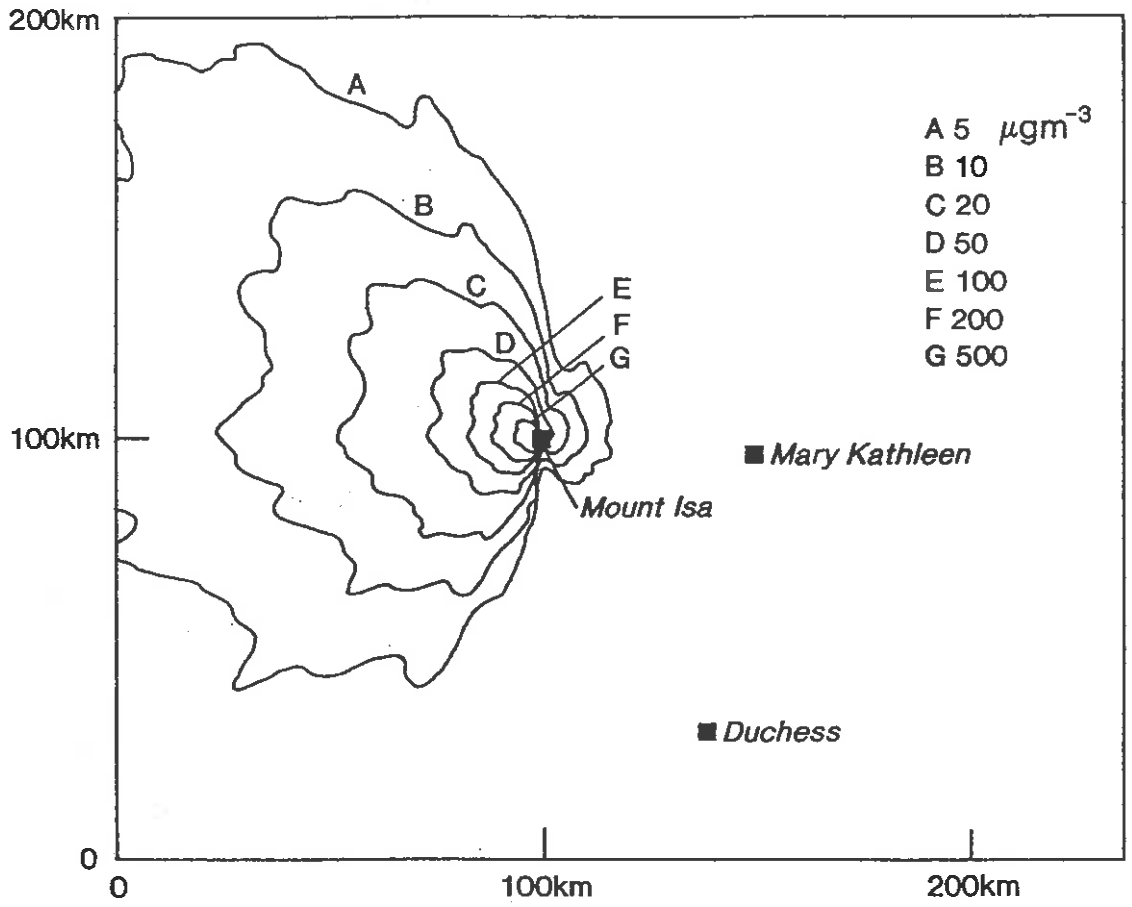

Figure 5 Isopleths of annual average ground level concentration of SO_2 for the year 1986/87 assuming 300 k tonne emissions.

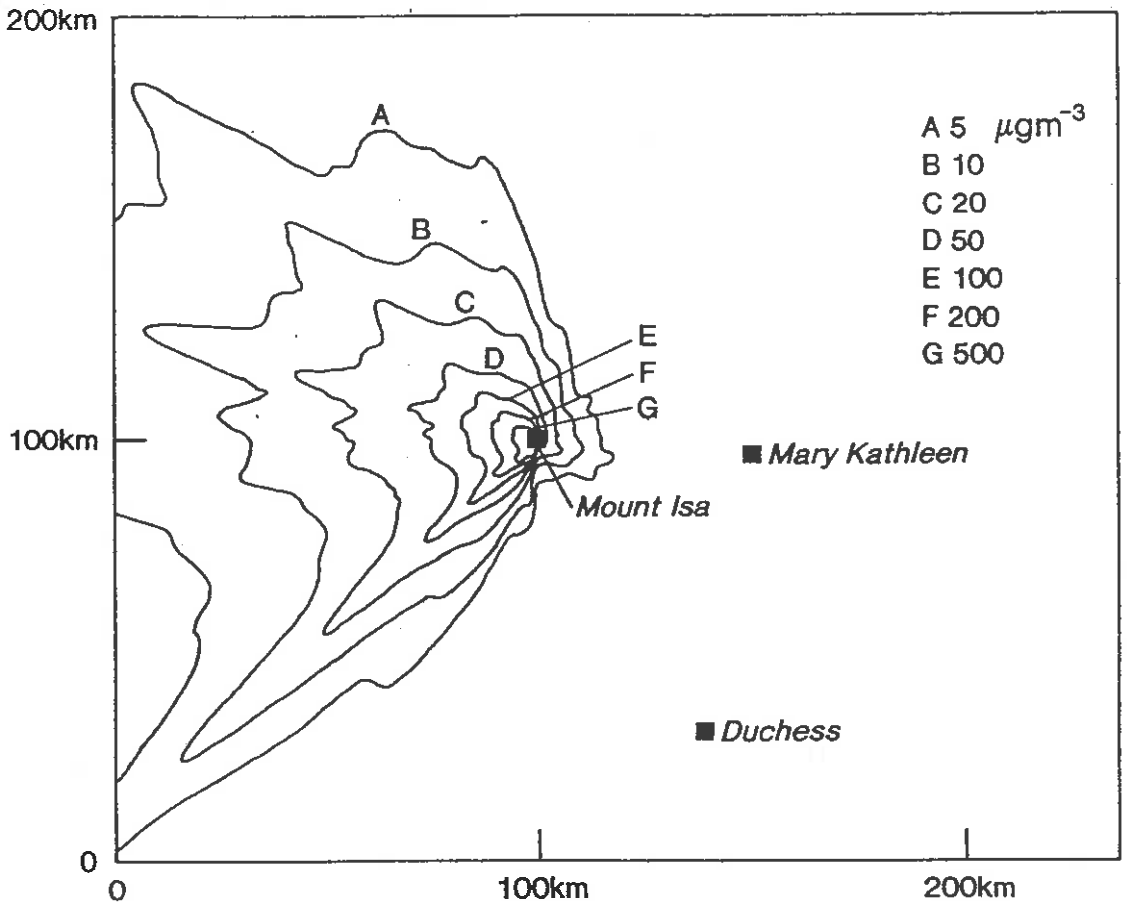

Figure 6 Isopleths of annual average ground level concentration of SO_2 for the year 1987/88 assuming 300 k tonne emissions.

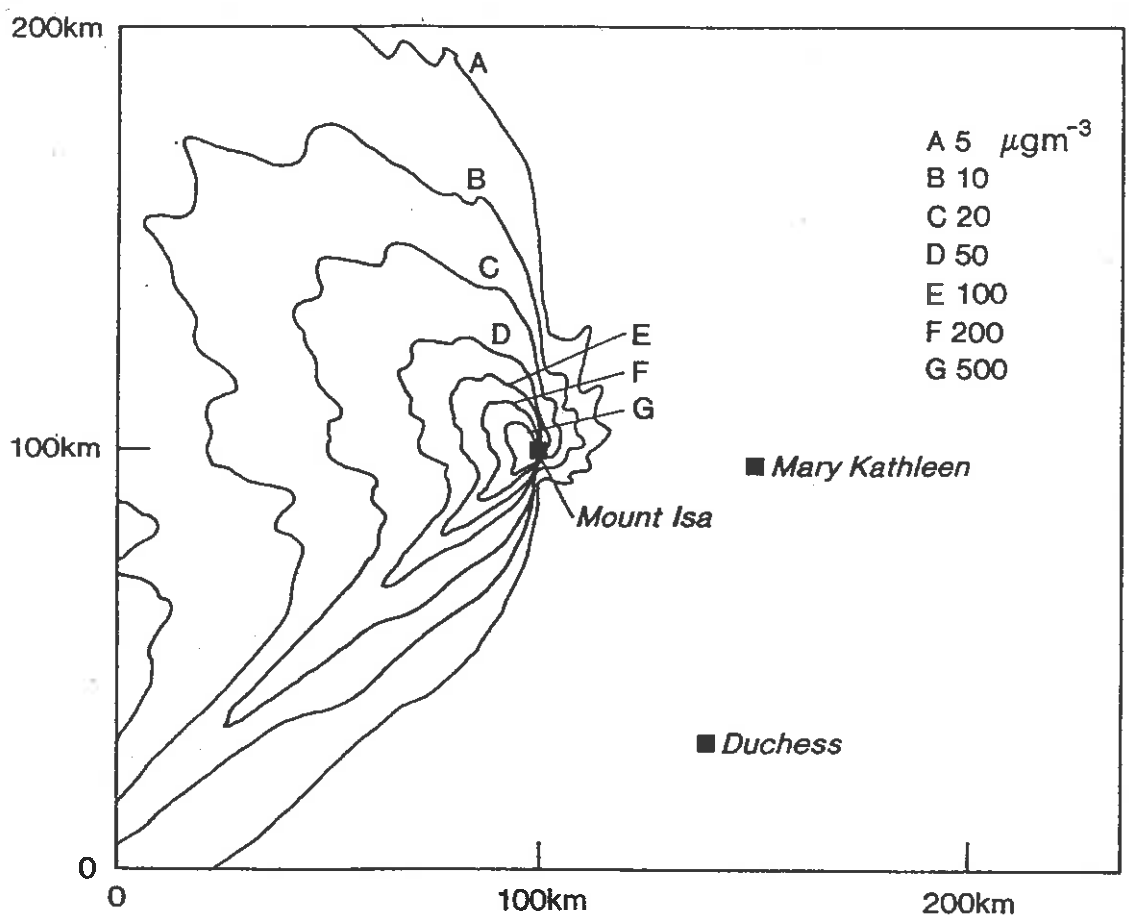

Figure 7 Isopleths of annual average ground level concentration of SO_2 for the year 1988/89 assuming 300 k tonne emissions.

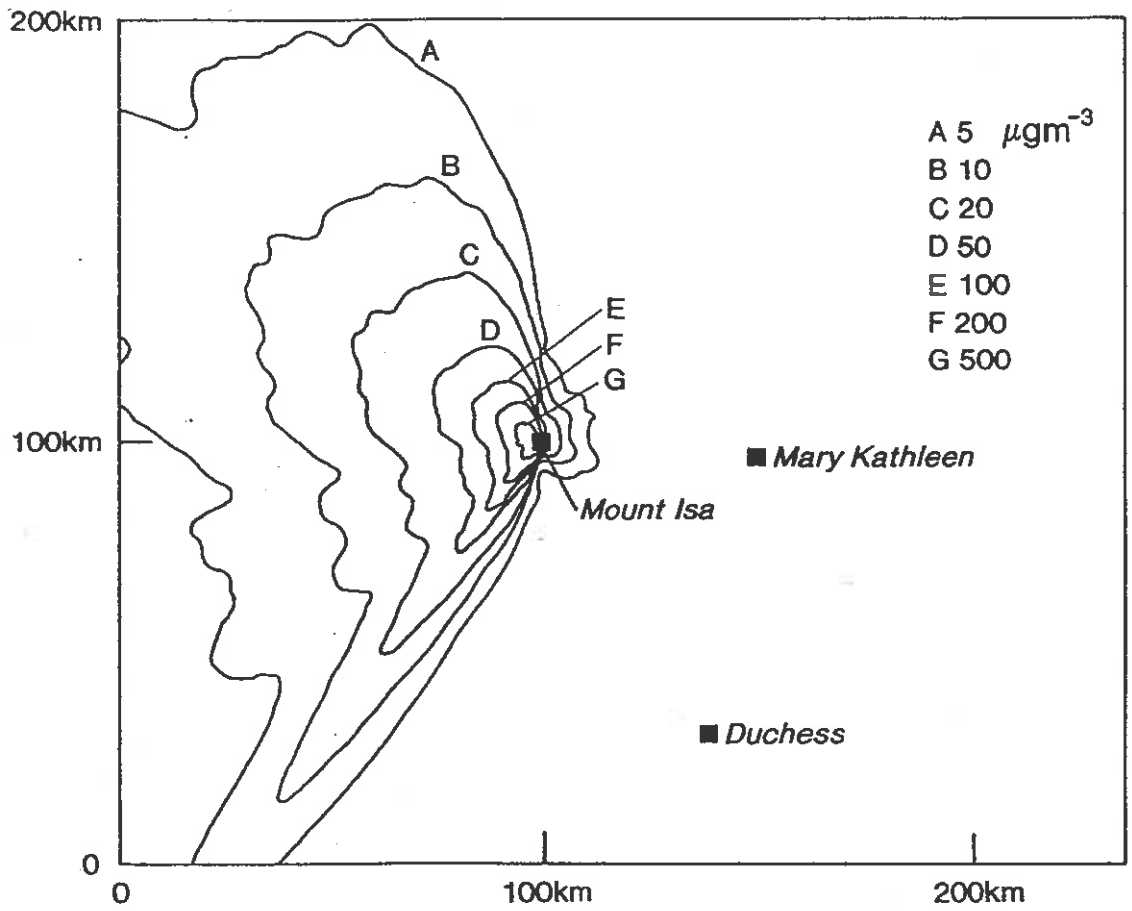

Figure 8 Isopleths of annual average ground level concentration of SO_2 for the year 1990/91 assuming 300 k tonne emissions.

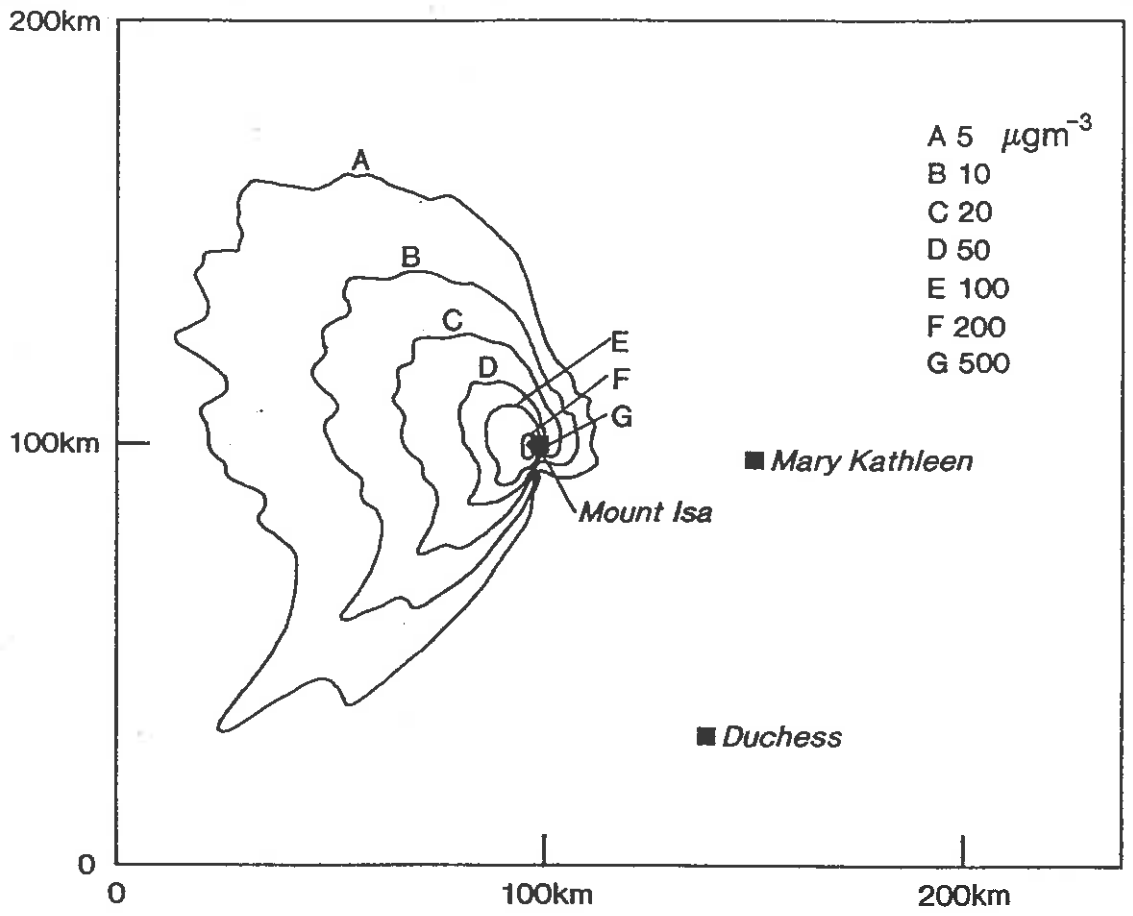

Figure 9 Isopleths of annual average ground level concentration of SO_2 using the four years of wind data assuming base case emissions.

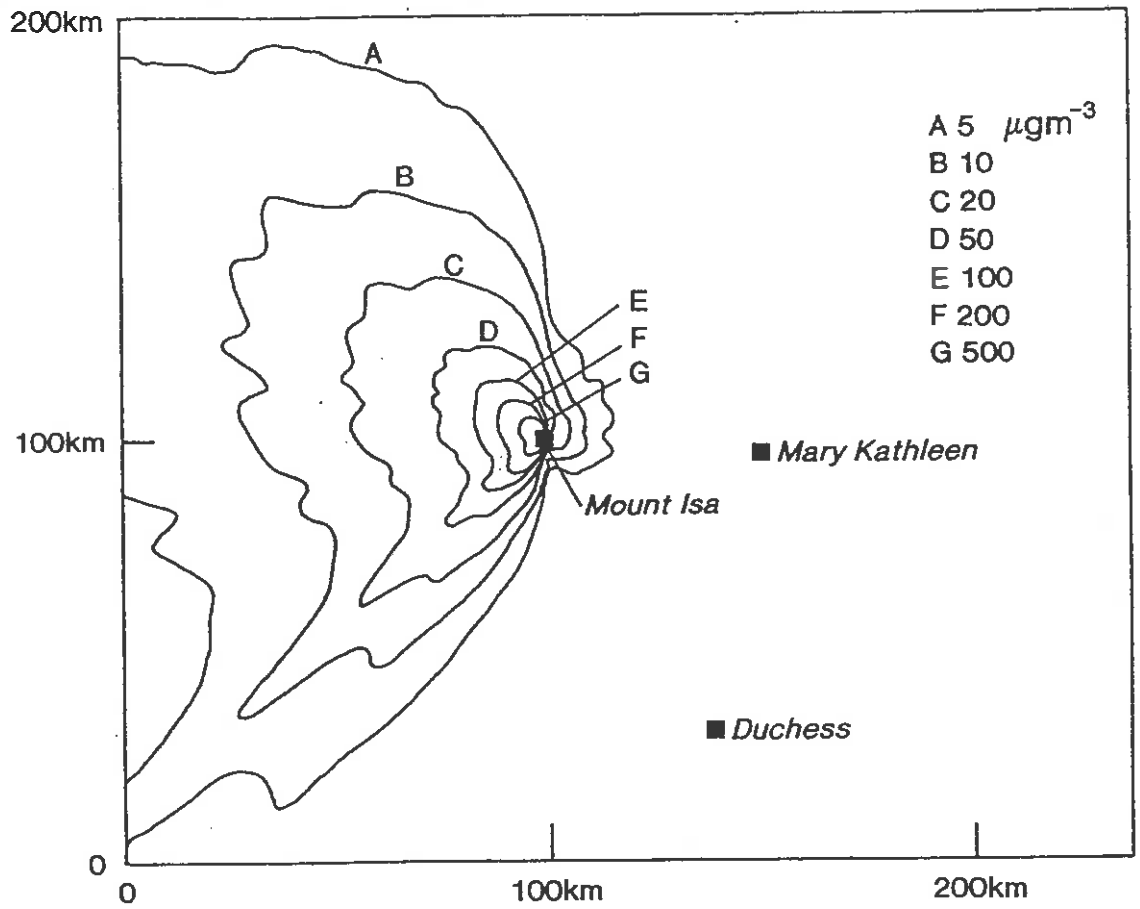

Figure 10 Isopleths of annual average ground level concentration of SO_2 using the four years of wind data assuming 300 K tonne emissions.

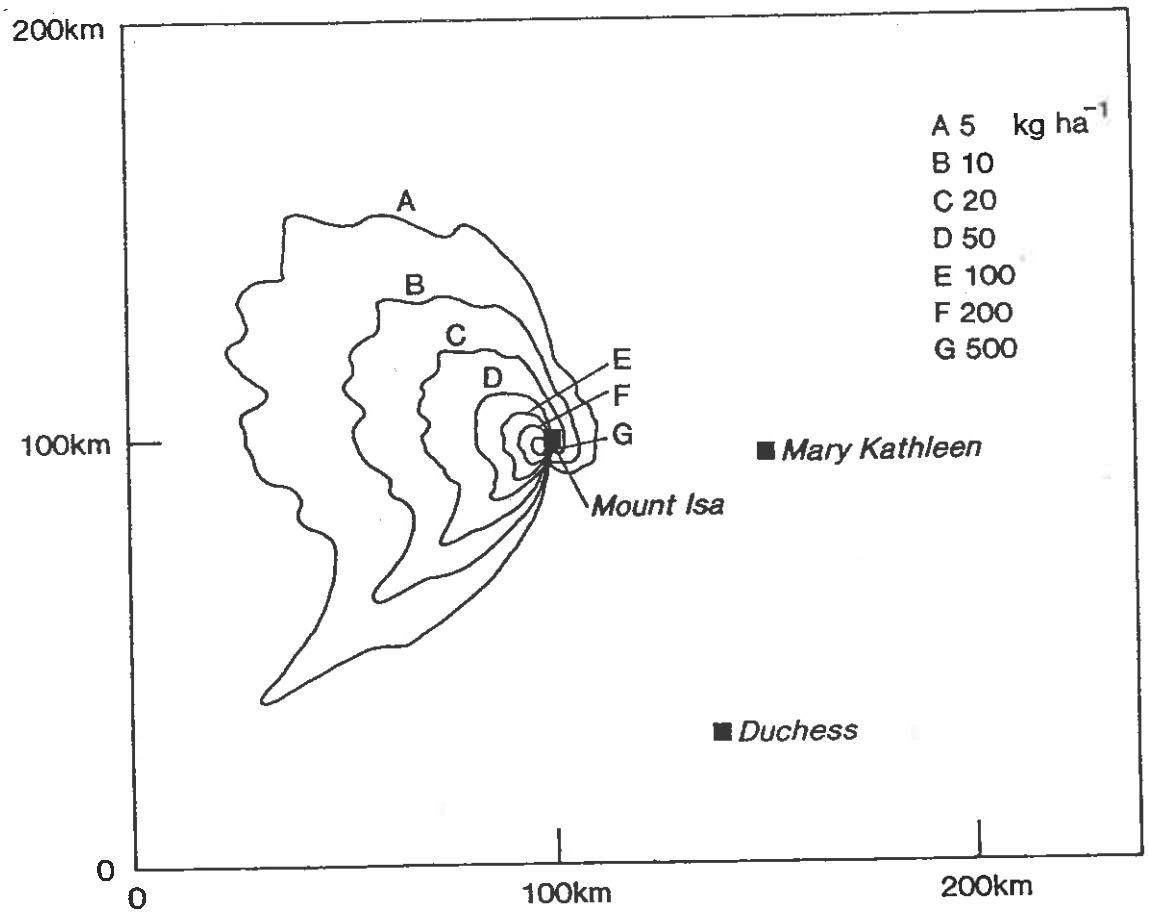

Figure 11 Isopleths of annual average dry deposition of SO_2 for the four year average and for base case emissions.

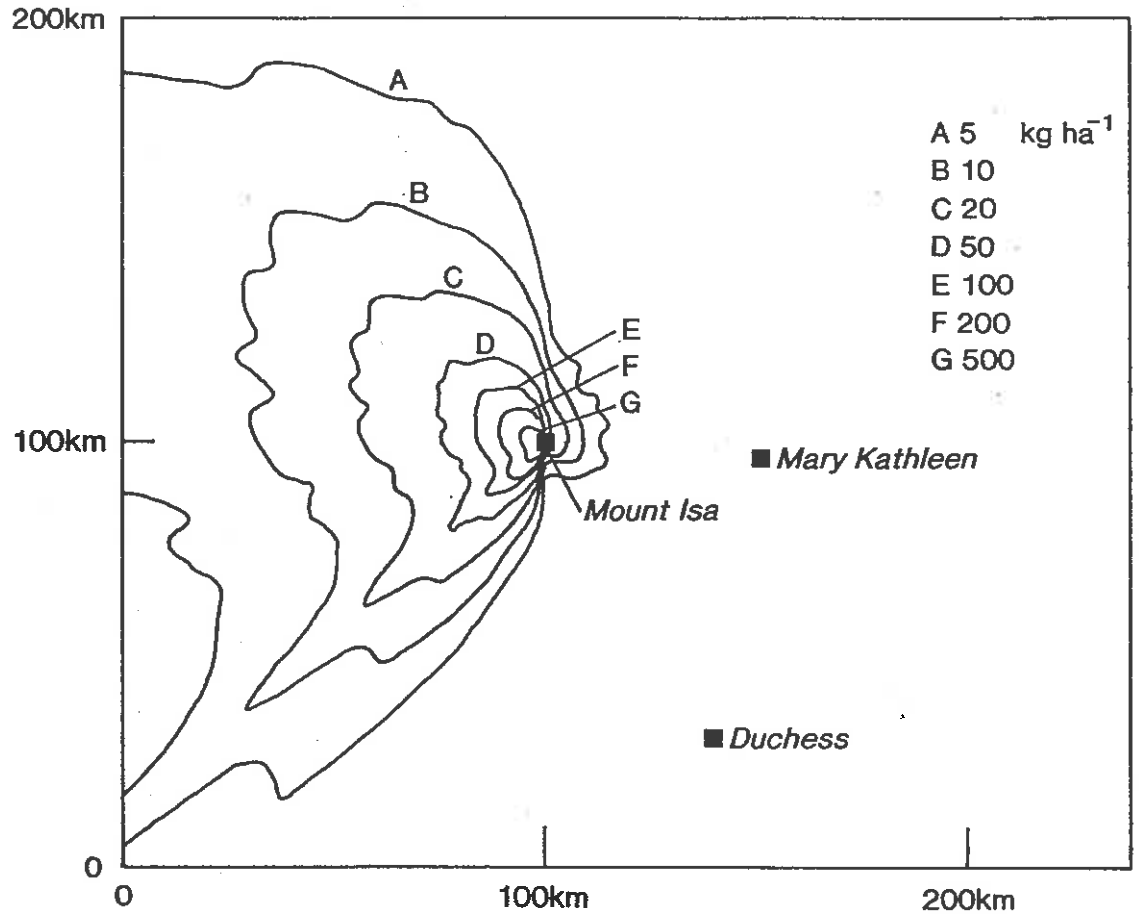

Figure 12 Isopleths of annual average dry deposition of SO_2 for the four year average and 300 k tonne emissions.

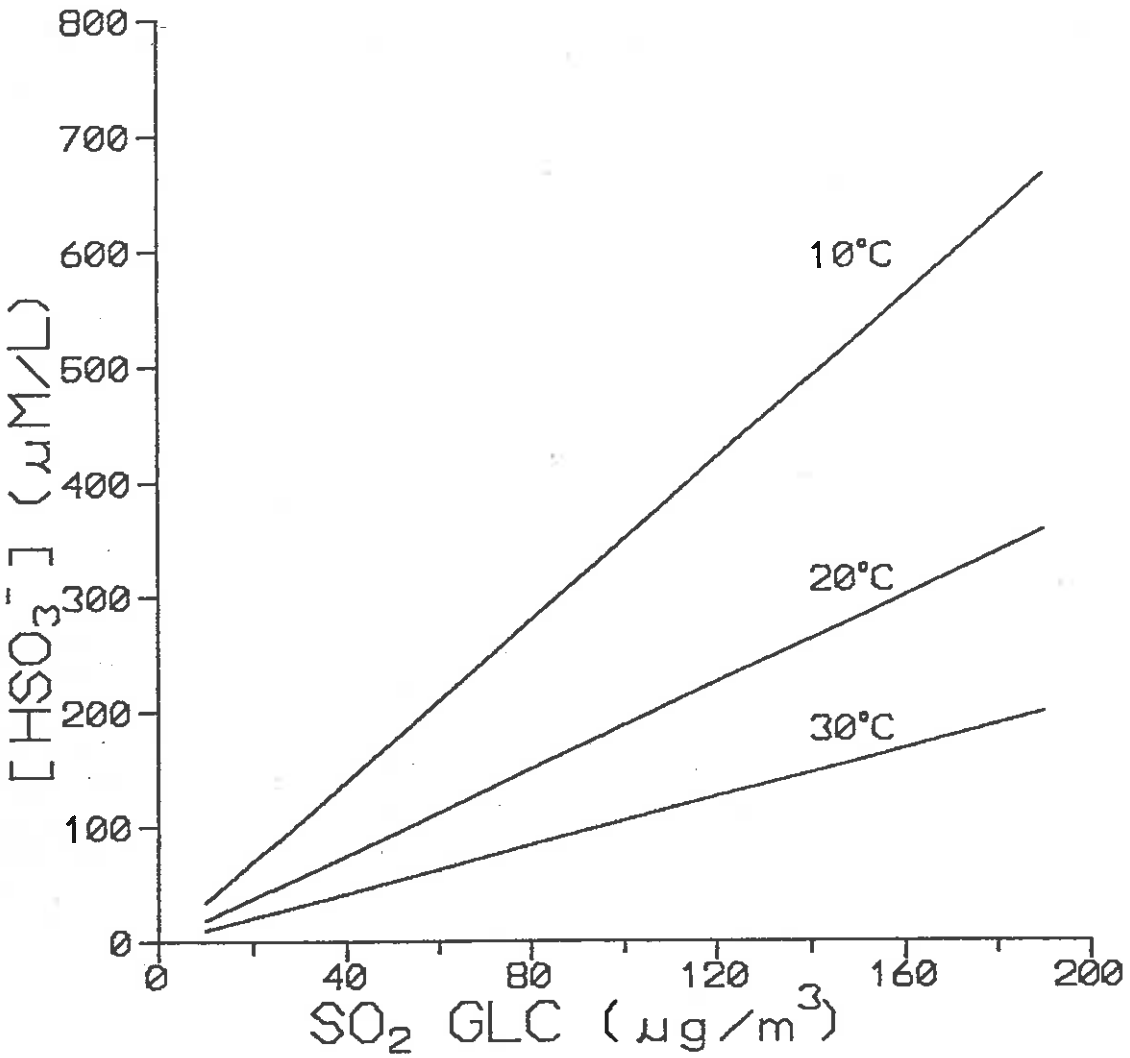

Figure 13 Calculations of the equilibrium concentrations of HSO_3^- in rain water as a function of SO_2 concentration and for different ambient temperatures.