CHAPTER 10

ANALYSIS OF AIR MASS BACK TRAJECTORIES

This chapter discusses several analyses of air mass trajectories in the PREVENT study area during the summer of 1990. Back trajectories from the three receptor sites, Marblemount, Tahoma Woods, and Paradise, are examined both graphically and statistically to assess where air masses resided before arriving at these sites, and the association between back trajectories and concentrations of sulfur and trace elements.

10.1 DESCRIPTION OF BACK TRAJECTORY MODEL

Air mass back trajectories were calculated using the ARL-ATAD model[1] which is a Lagrangian parcel model with a single variable depth transport layer. The base of the transport layer is always 300 m above the ground. For most time periods, the top of the transport layer is the lowest level within a critical inversion at which the potential temperature is 2°K above that at the inversion base. A critical inversion is defined as an inversion with a potential temperature lapse rate of at least 5°K/km. When no critical inversion exists, the transport layer top is assumed to be 3000 m above the ground. For trajectories that begin at night, the initial transport layer depth is approximated by $2\sigma_z$, where σ_z is the standard deviation of the vertical dispersion of a gaussian plume for stable conditions. This is used only until the first daytime period of the trajectory.

Average winds within the transport layer are interpolated both spatially and temporally from all available radiosonde data within 250 km. If there are no stations within 250 km, data from stations within 600 km are used. ATAD terminates the trajectory if there are no upper air data within 600 km. Complex terrain is not explicitly considered in the model, although the transport layer is always at least 300 m above the terrain near each radiosonde station.

A back trajectory is started from each receptor once every six hours for each particle monitoring period. ATAD calculates an air parcel position, or endpoint, every three hours backward or forward in time for a maximum of five days. Linear interpolation is used to generate an endpoint position for every hour for each trajectory.

10.2 GRAPHICAL ANALYSIS OF BACK TRAJECTORIES

The simplest analysis carried out with the back trajectory data was a qualitative graphical examination. For each receptor site, Marblemount, Paradise, and Tahoma Woods, a map of the back trajectories arriving during each 12-hour particulate monitoring period was created. Along with each map is a graph showing the ratios of the measured concentrations of 12 different chemical species to the maximum concentration of that species measured at that site during the study. These species include sulfur and the trace elements which are of interest in the Chemical Mass Balance (CMB) modeling. The maximum concentrations along with some other statistics are shown in Table 10-1. All trajectory maps are shown in Appendix 8 and CMB modeling was discussed in Chapter 9.

One use of these maps is to detect whether or not emissions from Centralia Power Plant could have influenced the particle concentrations at each receptor site during each monitoring period. Each 12-hour period was assigned a Centralia hit/no hit code of 0 (probably did not pass over Centralia), 1 (uncertain), or 2 (very likely that the trajectory passed over Centralia). The code assignments are based on qualitative examination of the maps. If the trajectory passed directly over Centralia or if a series of trajectories appeared to have swept across Centralia, a code of 2 was assigned. If all trajectories were from the north, east, or south, a code of 0 was assigned. A 1 was assigned to ambiguous cases, where the trajectory was from the general direction of Centralia, but not close enough to determine whether it was a hit or no hit with any confidence. A "hit" indicates only that air which arrived at the receptor site during the monitoring period probably passed over Centralia sometime during the previous five days. Because emission rates, dispersion, deposition, etc. are not taken into account, a hit does not necessarily imply that emissions from the power plant impacted the receptor site. For example, a code of 2 could be assigned for a day when the plant was not operating. Table 10-2 shows the percent of time when each hit/nohit condition was met at each receptor site. Tahoma Woods has the highest percentage (27%) of 12-hour periods when emissions from Centralia were very likely to be present. Results for Paradise and Marblemount are 15% and 9%, respectively.

Time plots of these codes and the sulfur concentrations at the receptor sites are shown in Figure 10-1. Also included in the same figure, are time lines of a similar hit/no hit code based on the results of the CMB modeling for Paradise and Tahoma Woods. The CMB hit/no hit codes show the relative amount of selenium which is attributable to coal burning at each site. See Chapter 9 for details.

From Figure 10-1, it is apparent that the highest sulfur concentration episodes at Paradise and Tahoma Woods are almost always associated with "hits" from Centralia Power Plant. However, this is not generally true for Marblemount.

It is also evident that the CMB model indicates some influence from coal burning on most days, but the trajectory model suggests that direct hits from the Centralia Power Plant are less frequent than this. The highest selenium concentration measured at Tahoma Woods, occurred on June 20 when the Centralia plant was not operating. This suggests that there are other coal-burning sources which influence particulate concentrations in the study area. Examination of the trajectory plots for individual days, indicates that there are probably at least two other sources, one located south of Mount Rainier National Park, possibly in or near Portland, OR, and the other located to the north or northeast, possibly in Canada.

Table 10-1. Summary statistics for species used in trajectory analyses. All concentrations are in units of ng/m^3. "No.0 obs" is the number of observations when the concentration was less than the minimum detection limit. "Min High" is the geometric mean plus the geometric standard deviation and is the minimum concentration which was considered to be high in Section 10.3. "Max Low" is the geometric mean minus the geometric standard deviation. Values lower than this are "low" in Section 10.4. "No. Hi" and "No. Low" are the number of observations which are high and low based on these criteria.

Species	Site	No of Obs	Max	Min	No. 0 obs	Geo. Mean	Min High	No Hi	Max Low	No Low
S	MARB	174	1475.76	52.62	0	406.97	740.43	33	223.69	22
	PARA	84	1773.53	4.47	0	310.43	939.35	9	102.59	10
	TAWO	177	1735.94	49.09	0	467.36	1000.55	31	218.31	28
ECHT	MARB	171	455.10	35.90	2	182.62	296.88	27	112.34	30
	PARA	77	618.40	11.80	3	153.96	321.17	10	73.80	9
	TAWO	170	623.90	21.10	1	179.46	324.55	22	99.24	27
Na	MARB	174	303.14	4.28	46	23.08	74.64	32	7.14	48
	PARA	84	114.01	5.0	24	18.27	48.20	14	6.93	26
	TAWO	177	405.18	5.0	25	29.67	85.57	24	10.29	36
Se	MARB	---								
	PARA*	73	0.40	0.01	25	0.06	0.21	10	0.02	25
	TAWO*	168	1.00	0.01	39	0.10	0.40	13	0.03	39
As	MARB	---								
	PARA *	73	0.25	0.01	66	0.01	0.03	9	0.01**	66
	TAWO*	168	0.83	0.01	155	0.01	0.03	16	0.01**	155
Cu	MARB	174	18.68	0.10	37	0.50	1.54	22	0.17	40
	PARA*	73	11.82	0.10	6	0.49	1.25	8	0.20	7
	TAWO*	168	4.82	0.10	2	0.83	1.73	29	0.40	18
Pb	MARB	174	54.75	0.39	4	1.54	3.03	19	0.78	21
	PARA*	73	5.35	0.10	5	0.77	2.06	12	0.29	13
	TAWO*	168	11.66	0.09	2	1.71	5.24	34	0.56	28
Br	MARB	174	3.25	0.10	3	1.38	2.44	21	0.78	19
	PARA*	73	2.66	0.07	0	0.75	1.82	10	0.31	13
	TAWO*	168	4.02	0.18	0	1.22	2.54	32	0.59	31
K	MARB	174	455.13	10.37	0	39.58	68.64	22	22.82	25
	PARA	84	599.74	0.10	1	28.92	89.31	8	9.36	12
	TAWO	177	451.04	0.10	0	39.88	81.24	23	19.57	31
Mn	MARB	174	3.55	0.10	10	0.95	2.02	22	0.45	24
	PARA	84	3.92	0.10	6	0.92	2.07	11	0.41	8
	TAWO	177	9.32	0.10	11	1.31	3.56	37	0.48	18
Si	MARB	174	258.32	1.00	1	46.73	115.15	29	18.96	32
	PARA	84	376.76	1.00	0	52.23	165.23	15	16.51	17
	TAWO	177	296.70	1.0	6	43.51	140.47	27	13.48	26

* XRF data used
** Min low set to value used for 0

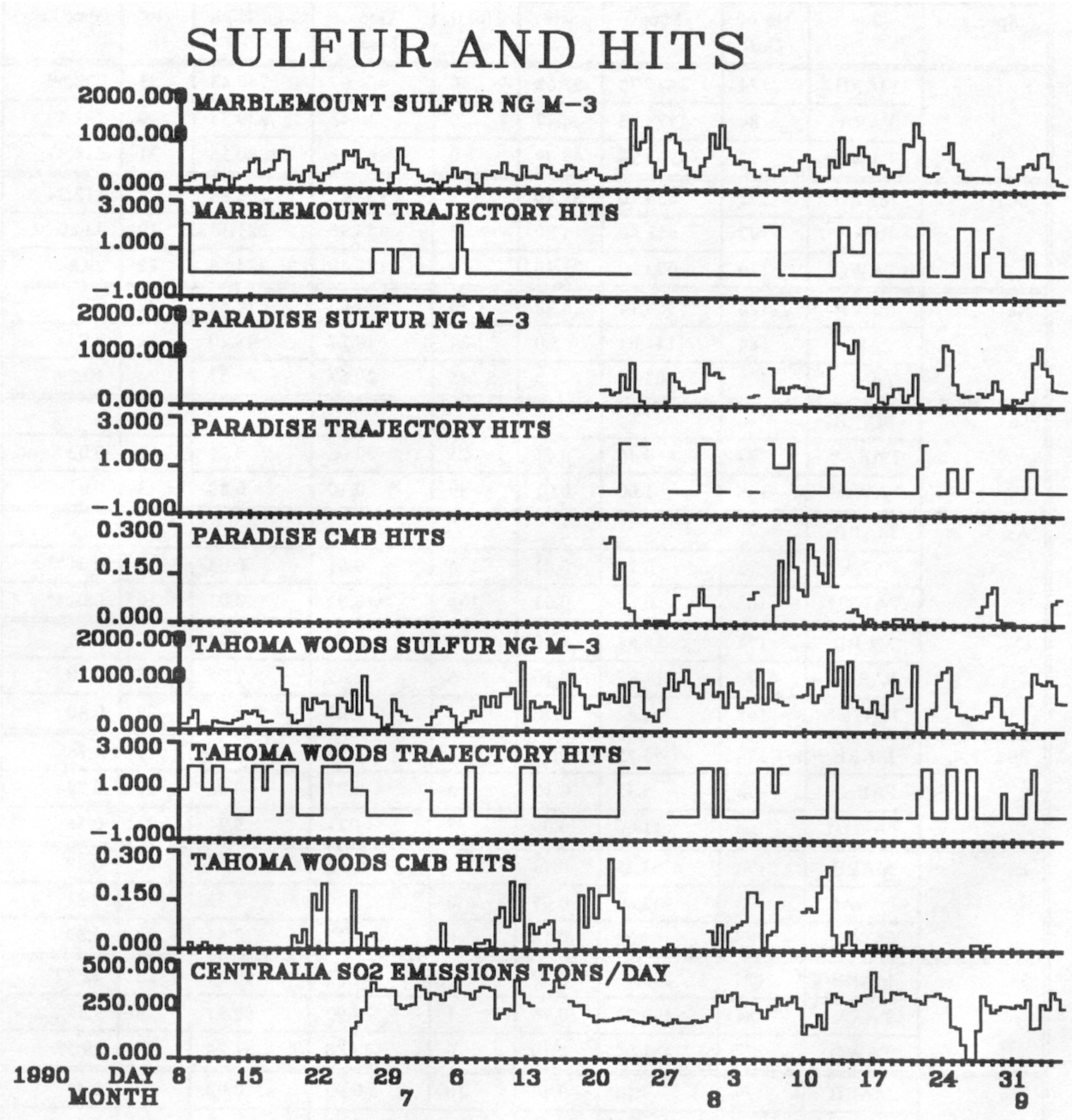

Figure 10-1. Sulfur concentrations, trajectory hit/nohit code, (see Table 10-2), relative amount of Se from coal-fired power plants based on CMB modeling (see Chapter 9), and SO_2 emission from Centralia Power Plant.

Table 10-2. Conditions for each Centralia hit or no hit code and percent of time when each condition was met at each receptor site.

The back trajectory...	Code	MARB 165 obs	PARA 79 obs	TAWO 171 obs
is very likely to have passed over Centralia.	2	15 (9%)	12 (15%)	44 (27%)
may have passed over Centralia (uncertain).	1	15 (9%)	10 (13%)	14 (9%)
probably did not pass over Centralia.	0	135 (82%)	57 (72%)	107 (65%)

The results for each site are summarized below:

10.2.1 Paradise

The highest sulfur concentrations at Paradise occurred during August 12-14 when the 12-hour average concentrations peaked at 1774 ng/m^3 and were never lower than 832 ng/m^3. During August 12-13 the trajectory model indicates that emissions from Centralia were "hitting" Paradise, while the CMB model predicted a maximum power plant influence. The second highest sulfur concentration occurred during August 14-15 when the trajectory model showed no Centralia influence and the CMB model showed little coal-fired power plant impact. The high sulfur concentrations during the second half of the episode may be due to some other source, possibly in the Portland area. Figures 10-2 and 10-3 illustrate the different back trajectory patterns which existed during the first and second half of the episode, respectively. Figure 10-2 shows the trajectories which arrived at Paradise for 12 hours beginning at 8/12/90 20:00 when sulfur and selenium were at 100% of maximum. Figure 10-3 shows the trajectories which arrived for 12 hours beginning 8/14/90 20:00. Sulfur and selenium were both approximately 80% of maximum during this time period. The pattern was similar for the other two time periods during the second half of the episode and showed trajectories arriving from the south.

A second episode with slightly lower sulfur concentrations occurred August 23 and 24 when the 12-hour averages at Paradise ranged from 506 to 1313 ng/m^3. During August 23 trajectories arrived from the northwest, probably bringing air from the Seattle-Tacoma urban area. Although sulfur concentrations were high, Selenium concentrations were less than 40% of maximum. On August 24, although trajectories were still from the north, they were farther west. Selenium concentrations were around 70% of maximum for the 12 hours beginning 8/24/90 8:00. Figures 10-4 and 10-5 show the back trajectories for the time periods beginning 8/23/90 20:00 and 8/24/90 8:00, respectively. CMB model results for these two days also indicated that the influence from coal burning was negligible.

Another high sulfur episode with 12-hour duration concentrations ranging from 690 to 1245 ng/m^3 occurred during September 1-3. The maximum was during the period beginning 9/2/90 8:00 when back trajectories indicate the air arrived from the Seattle area. However,

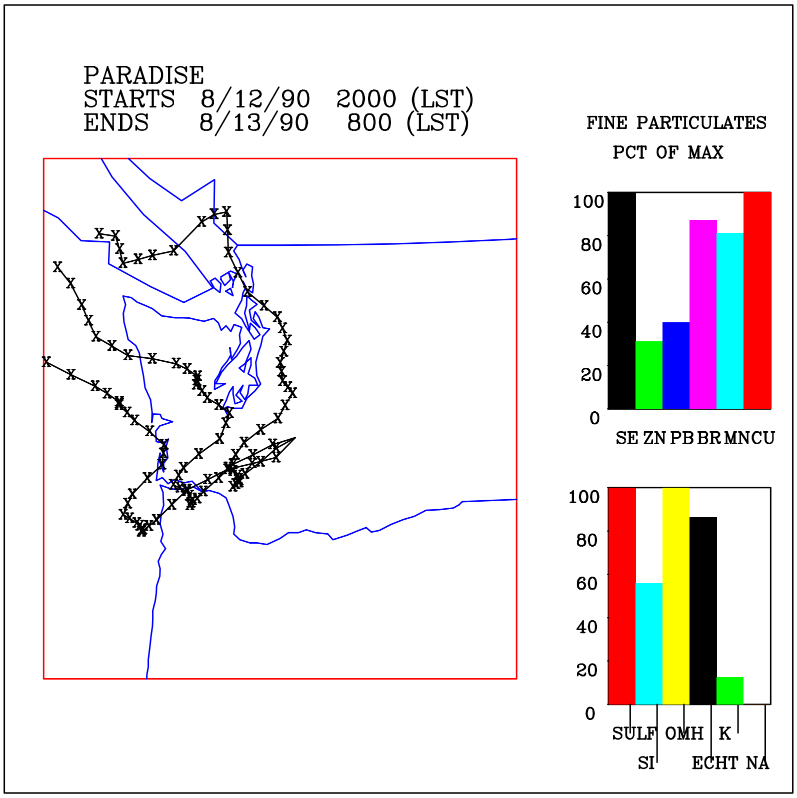

Figure 10-2. Back trajectories from Paradise and ratios of several particulate species to their maximums for 12 hours beginning 8/12/90 at 20:00. Each "X" represents 3 hours.

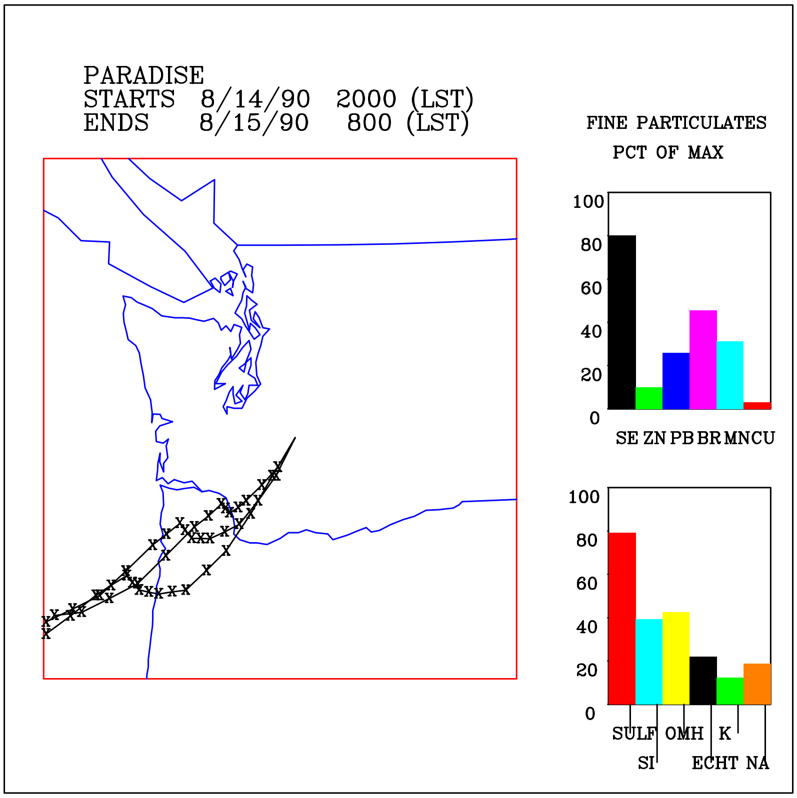

Figure 10-3. Back trajectories from Paradise and ratios of several particulate species to their maximums for 12 hours beginning 8/14/90 at 20:00. Each "X" represents 3 hours.

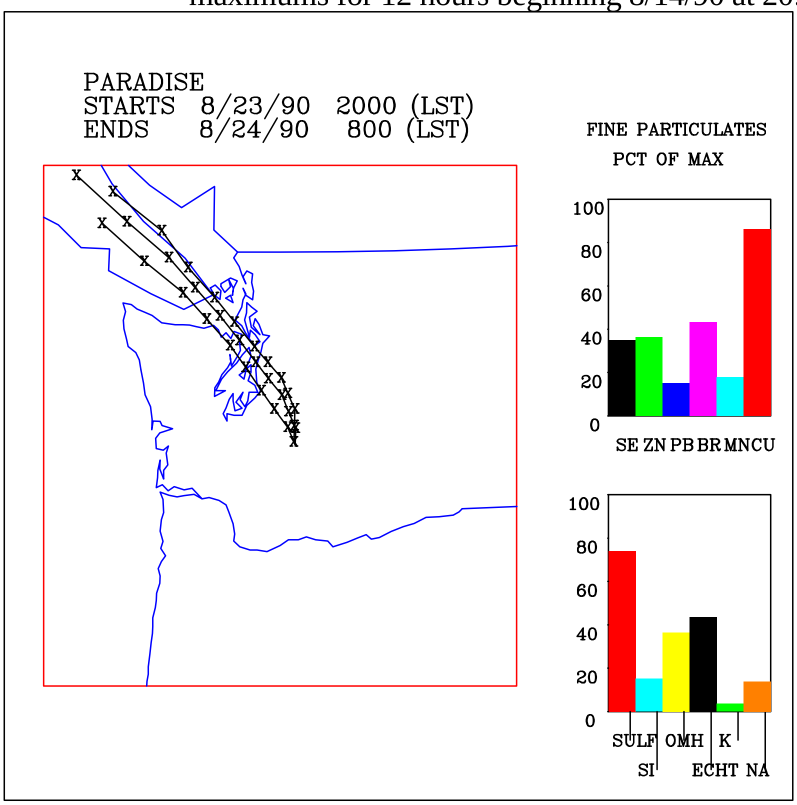

Figure 10-4. Back trajectories from Paradise and ratios of several particulate species to their maximums for 12 hours beginning 8/23/90 at 20:00. Each "X" represents 3 hours.

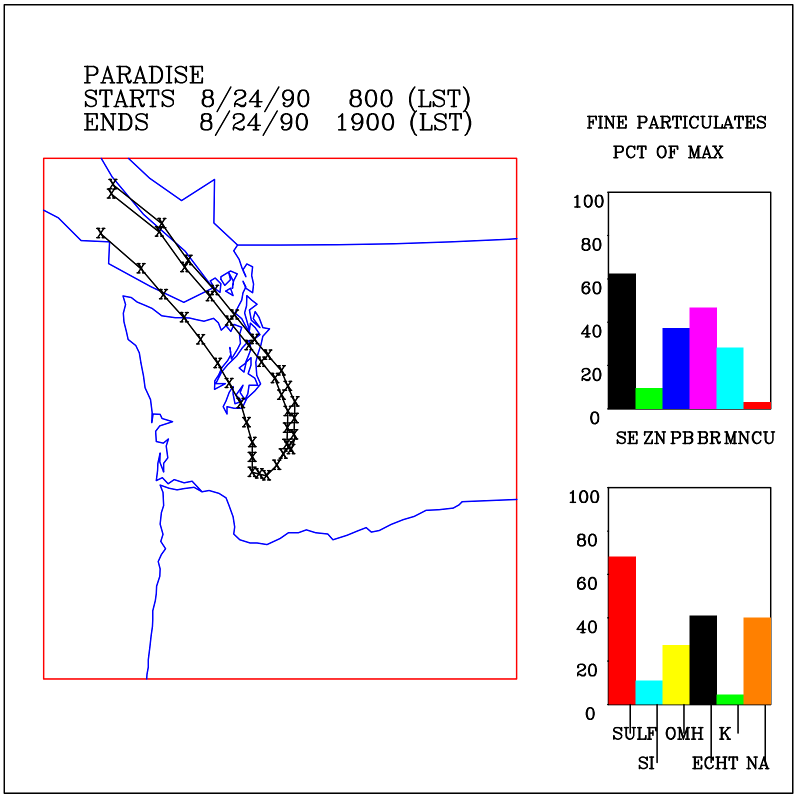

Figure 10-5. Back trajectories from Paradise and ratios of several particulate species to their maximums for 12 hours beginning 8/24/90 at 8:00. The "X"s are 3 hours apart.

trajectories arriving during the previous 12 hours, when the concentration was 947 ng/m^3 (beginning 9/1/90 20:00) appear to have passed over Centralia. No CMB modeling was performed for this time period because the high sensitivity trace elements were not available.

Six additional episodes when the sulfur concentration was greater than average for one or two 12-hour time periods also occurred at Paradise (see Figure 10-1). Four of these appear to be totally or partially associated with air masses arriving from Centralia.

10.2.2 Marblemount

The highest sulfur concentrations at Marblemount occurred during several time periods between July 23 and August 2. The maximum 12-hour concentration was 1476 ng/m^3 on 7/23/90 8:00. There was no evidence to support transport from Centralia for any of these time periods. However, there were insufficient upper air data to calculate back trajectories for the time periods with the first and third (7/26/90 20:00) highest concentrations. For the time period with the second highest concentration (7/24/90 20:00) there were sufficient data only for shortened trajectories. The trajectories which are available during July 23-August 2 all indicate transport from the west and north. An example, 7/31/90 8:00, is shown in Figure 10-6.

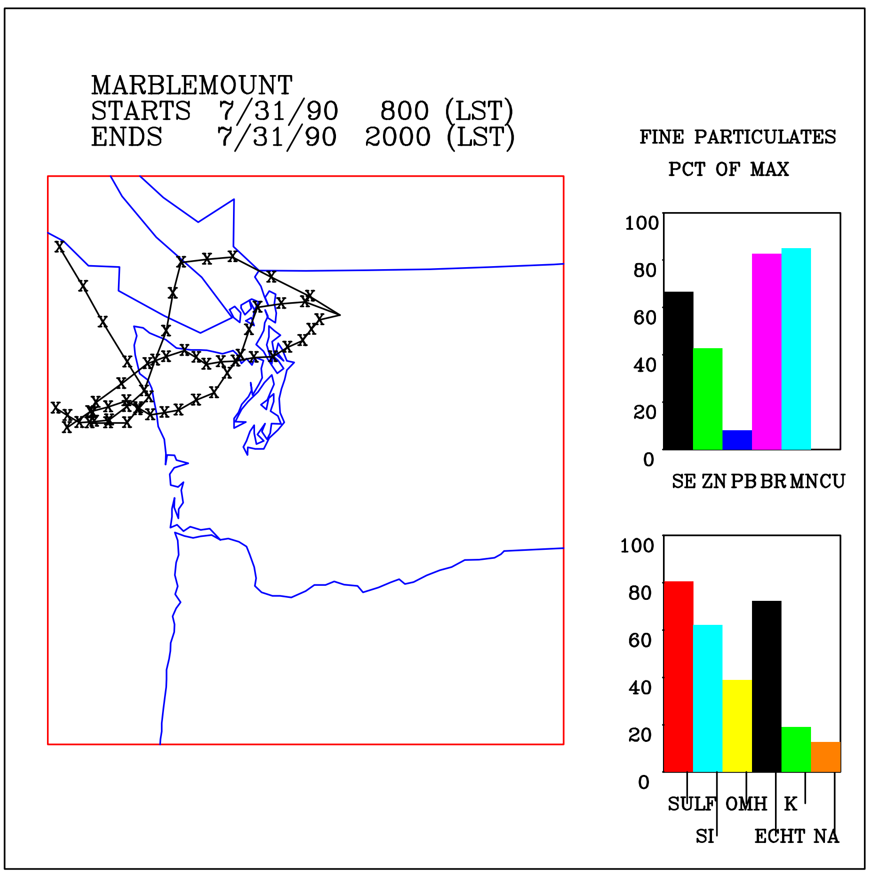

Figure 10-6. Back trajectories from Marblemount and ratios of several particulate species to their maximums for 12 hours beginning 7/31/90 8:00. Each "X" represents 3 hours.

Another episode with sulfur concentrations ranging from 959 to 1437 ng/m^3 occurred during four consecutive time periods from 8/19/90 20:00 to 8/21/90 8:00. The first two time periods had trajectories arriving directly from the northeast. The third, shown in Figure 10-7, had trajectories from the northeast, but with long loops back to the south, and the fourth time

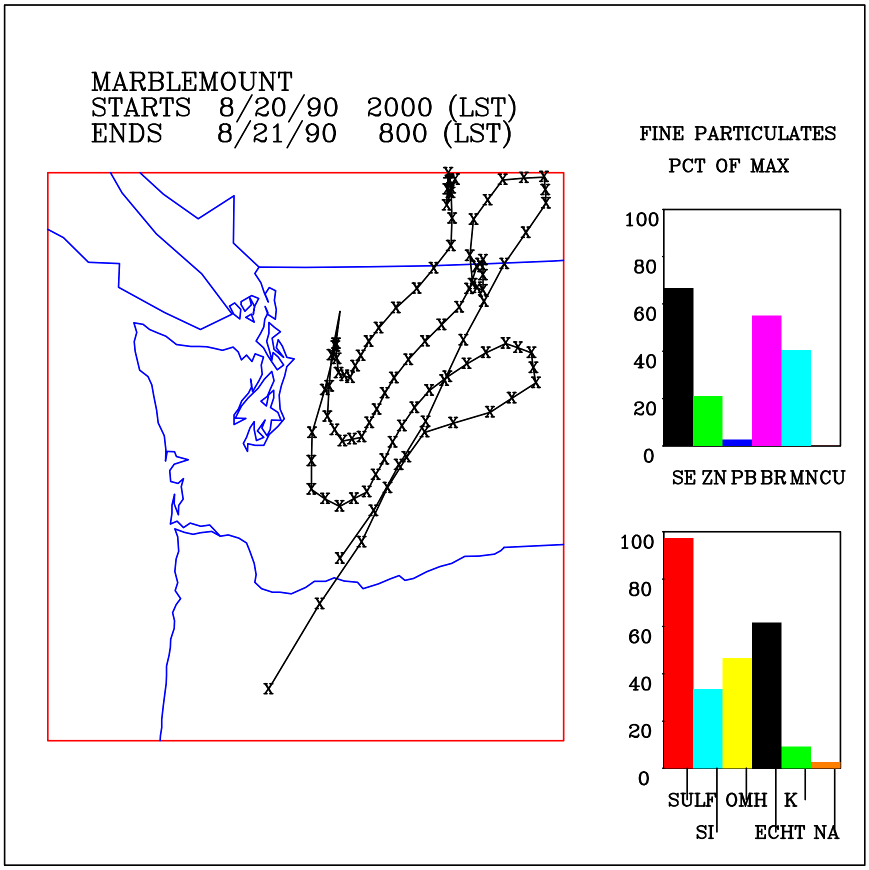

Figure 10-7. Back trajectories from Marblemount and ratios of several particulate species to their maximums for 12 hours beginning 8/20/90 20:00. Each "X" represents 3 hours.

period was similar to the third, but with southerly loops which were farther west and could have passed over Centralia.

There were two additional time periods when the sulfur concentrations were greater than 1000 ng/m^3 at Marblemount. These were 8/13/90 8:00 and 8/24/90 8:00. The first was associated with southwesterly trajectories which could be associated with emissions from Centralia, as well as from the Seattle-Tacoma urban area, and the second had trajectories which were from the north and northwest. These are shown in Figures 10-8 and 10-9.

No CMB modeling was carried out for Marblemount because there were no high sensitivity trace element data available.

10.2.3 Tahoma Woods

The highest sulfur concentration at Tahoma Woods was 1735 ng/m^3 on 8/12/90 8:00 during the same August 12-14 episode when the highest concentrations were measured at Paradise. Back trajectories for Tahoma Woods during this time period were similar to those for Paradise, which is not surprising since the sites are close together. Trajectories on August 12 pass near Centralia, but also cross the Seattle-Tacoma urban area and areas north and east. On August 13 and 14 the trajectories are more southwesterly. Selenium concentrations on all of these days were similar to Paradise. However, the highest concentration during these days was less than 50% of the maximum. Back trajectories for 8/12/90 8:00 are shown in Figure 10-10.

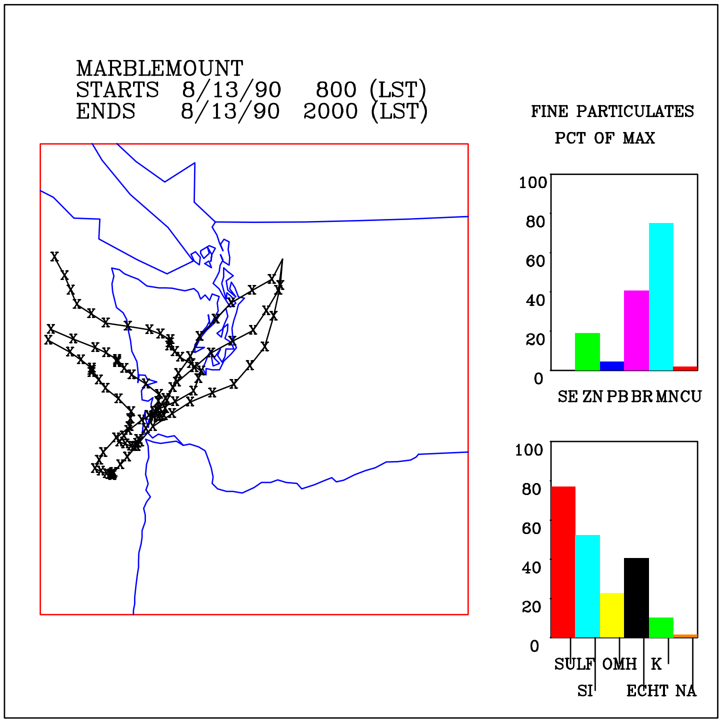

Figure 10-8. Back trajectories from Marblemount and ratios of several particulate species to their maximums for 12 hours beginning 8/13/90 8:00.

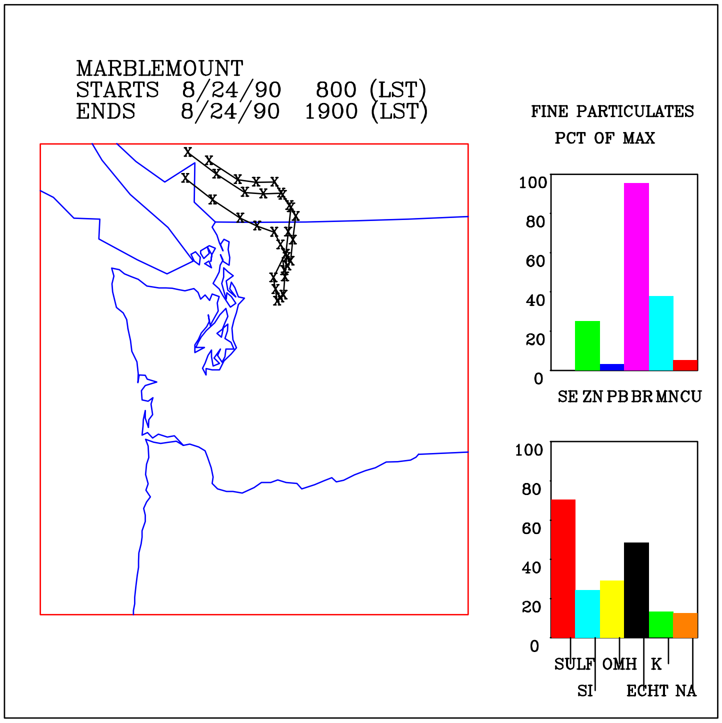

Figure 10-9. Back trajectories from Marblemount and ratios of several particulate species to their maximums for 12 hours beginning 8/24/90 8:00.

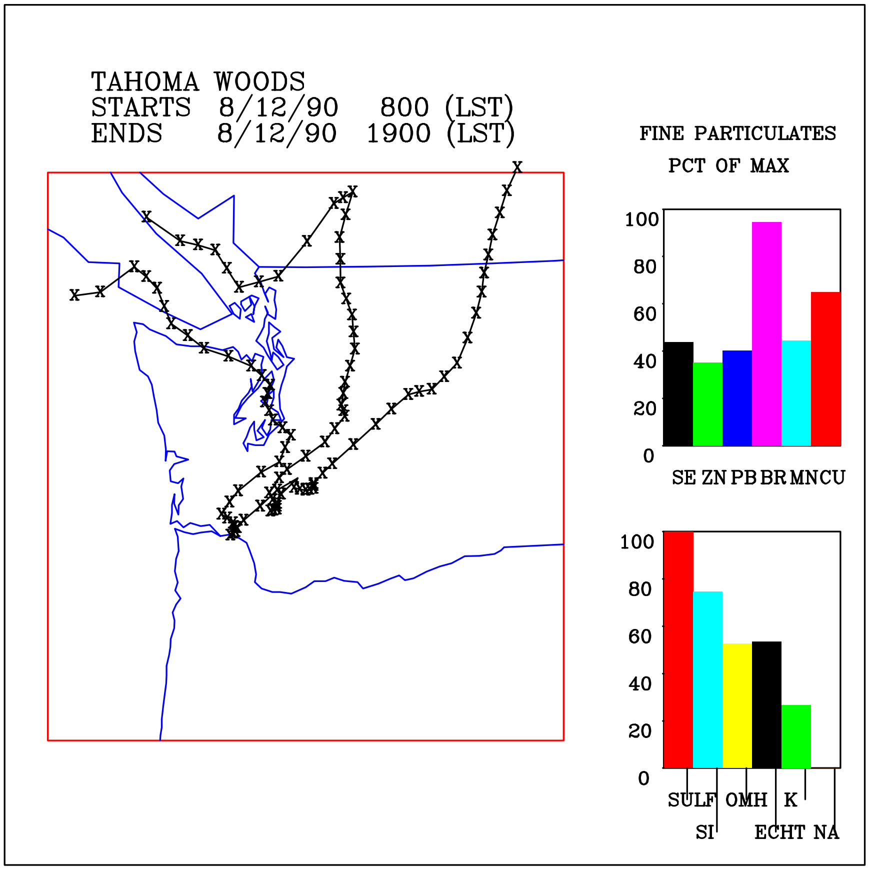

Figure 10-10. Back trajectories from Tahoma Woods and ratios of several particulate species to their maximums for 12 hours beginning 8/12/90 8:00.

The CMB results for this time period are also similar to Paradise. CMB analysis showed that coal-fired power plant signatures were strong on August 12 and 13 while on subsequent days the signal dropped to almost zero (see Figure 9-1).

There were high sulfur concentrations (1117-1368 ng/m^3) at Tahoma Woods on August 23 and 24. Back trajectories during all of these time periods were from the northwest, which traversed the urban area. Only one time period, 8/24/90 8:00 had a trajectory which appears to have crossed Centralia. Selenium concentrations during all of these time periods were less than 40% of the maximum. The CMB analysis showed little if any coal-fired power plant influence. Again these results were similar to Paradise.

Another period of high sulfur at Tahoma Woods was September 1-3 when concentrations were 1002-1239 ng/m^3. Trajectories during this time started out westerly (probably crossing Centralia) on 9/1/90 8:00 and gradually swung around to northerly on 9/3/90 20:00. High sensitivity selenium data were not available for these days and CMB analyses were not done. High concentrations during the middle time periods were probably mostly due to emissions in the urban corridor. This is similar to what was discussed for Paradise for these same days.

Some other time periods with high sulfur were from 7/8/90 to 7/12/90 (the highest concentration was 1442 ng/m^3) when the CMB analysis showed increasing coal-fired power plant influence. The air mass was likely to have passed over Centralia at the beginning and end of this episode. Other time periods that corresponded to high sulfur are; 8/20/90 20:00 (1401 ng/m^3) when the trajectories were from the south and west, possibly from Portland; 8/5/90 (1310 ng/m^3) when trajectories passed over Centralia then looped south, east and north, crossing Vancouver Island; 6/17/90 20:00 (1293 ng/m^3) and 7/17/90 8:00 (1200 ng/m^3) when the trajectories were from the northwest, passing through the urban corridor; 7/28/90 20:00 (1283 ng/m^3) when the trajectories were from the northeast; 8/18/90 20:00 (1115 ng/m^3) when the trajectories were from the south. Figures 10-11 through 10-14 illustrate some of these various trajectory patterns which were associated with high sulfur concentrations at Tahoma Woods.

During many time periods when trajectories indicated a hit from Centralia, the CMB analysis also showed a coal-fired power plant influence. However, there were several time periods where CMB results showed coal-fired power plant influence when trajectories clearly showed transport from directions other than Centralia.

10.3 STATISTICAL ANALYSIS OF BACK TRAJECTORIES AND PARTICLE DATA

10.3.1 Methodologies

The methodologies used for the residence time, conditional probabilities, and source contribution functions are briefly described here.

10.3.1.1 Residence Time

The area bounded by 30 and 60 degrees N latitude and 135 and 90 degrees W longitude is divided into 1/4 degree latitude by 1/4 degree longitude grid cells. The overall residence time for each grid cell is defined as the probability that if a trajectory arrived at the receptor it passed though that grid cell. High and low concentration residence times are similar except only trajectories which arrived at the receptor when the concentration was greater than and less than, respectively, a selected cutoff value are considered. Determination of high and low values are discussed in Section 10.3.6. The overall, high concentration, and low concentration residence times are defined for each grid cell by:

$$\begin{aligned} ORT_{i,j} &= \frac{1}{N}\sum_{t=1}^{T} n_{i,j,t} \\ HRT_{i,j} &= \frac{1}{N}\sum_{t=1}^{T} h_{i,j,t} \\ LRT_{i,j} &= \frac{1}{N}\sum_{t=1}^{T} l_{i,j,t} \end{aligned} \tag{10-1}$$

where n is the number of endpoints falling in the grid at longitude i and latitude j before the trajectory arrived at the receptor during measurement period t; h is the number of endpoints associated with trajectories which arrived at the receptor when the concentration was high; and l is the number of endpoints associated with trajectories which arrived when the concentration was low. T is the total number of time periods and N is the total number of endpoints throughout the domain for all time periods.

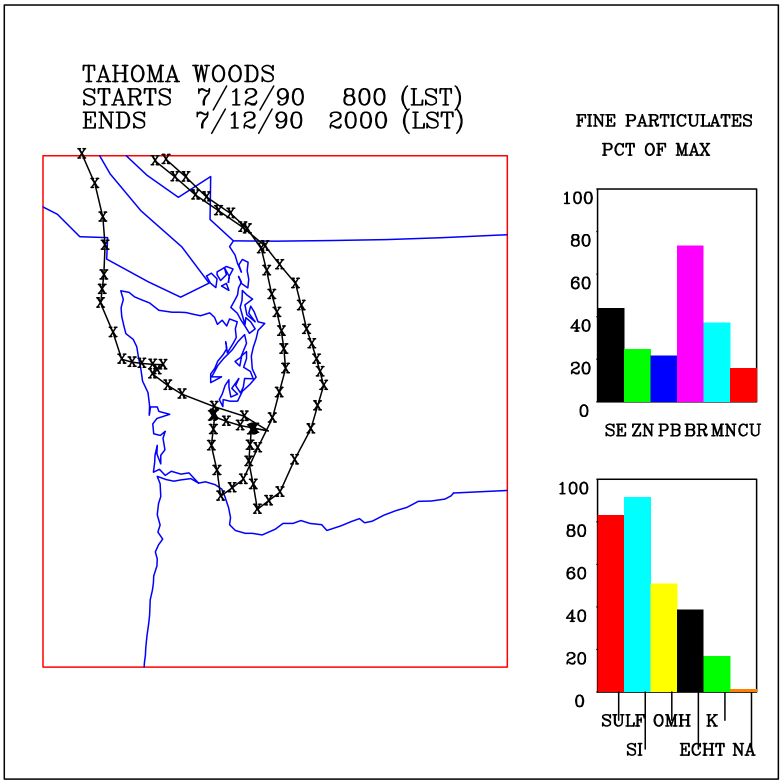

Figure 10-11. Back trajectories from Tahoma Woods and ratios of several particulate species to their maximums for 12 hours beginning 7/12/90 8:00.

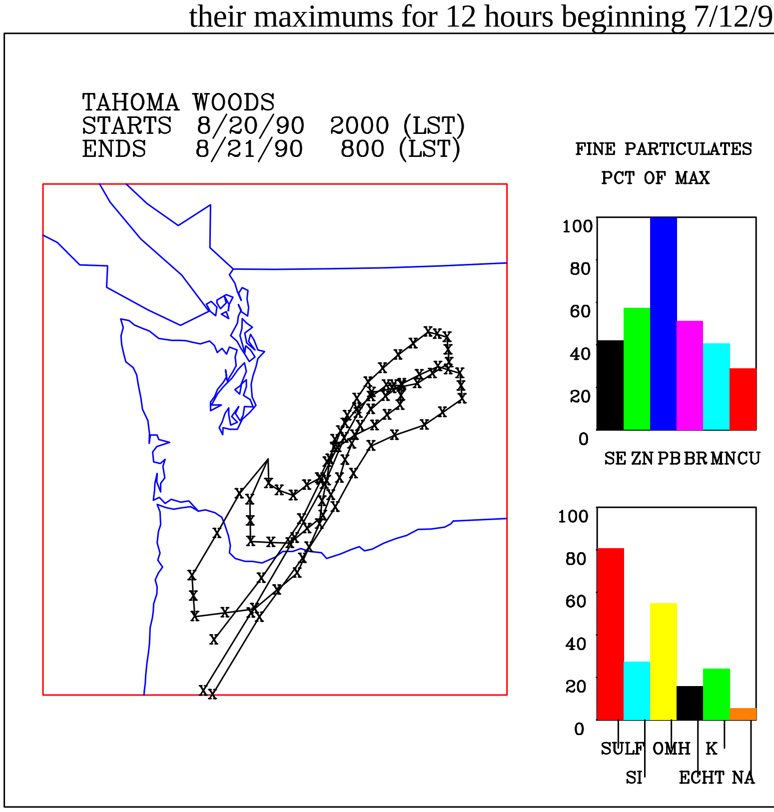

Figure 10-12. Back trajectories from Tahoma Woods and ratios of several particulate species to their maximums for 12 hours beginning 8/20/90 20:00.

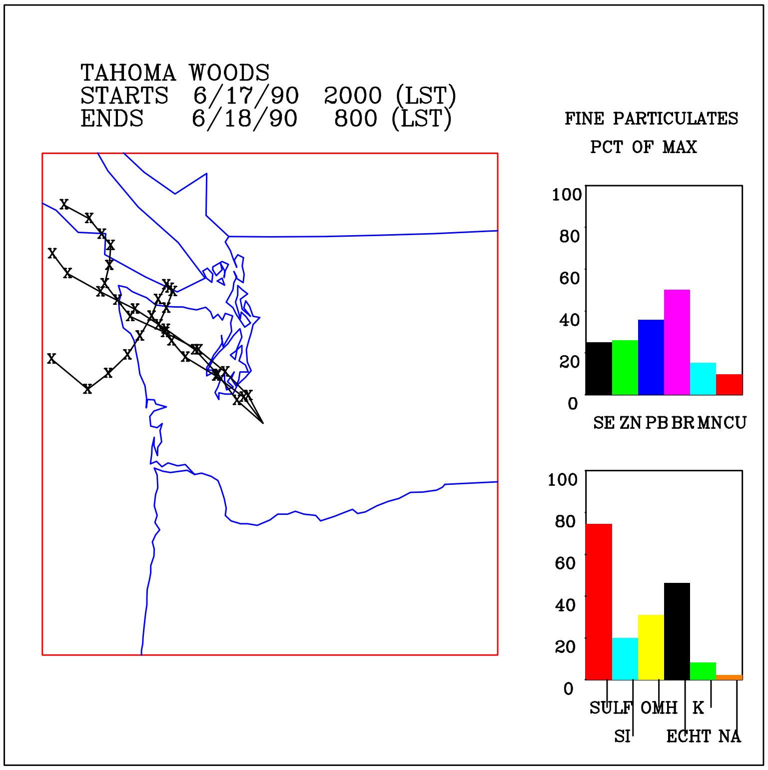

Figure 10-13. Back trajectories from Tahoma Woods and ratios of several particulate species to their maximums for 12 hours beginning 6/17/90 20:00.

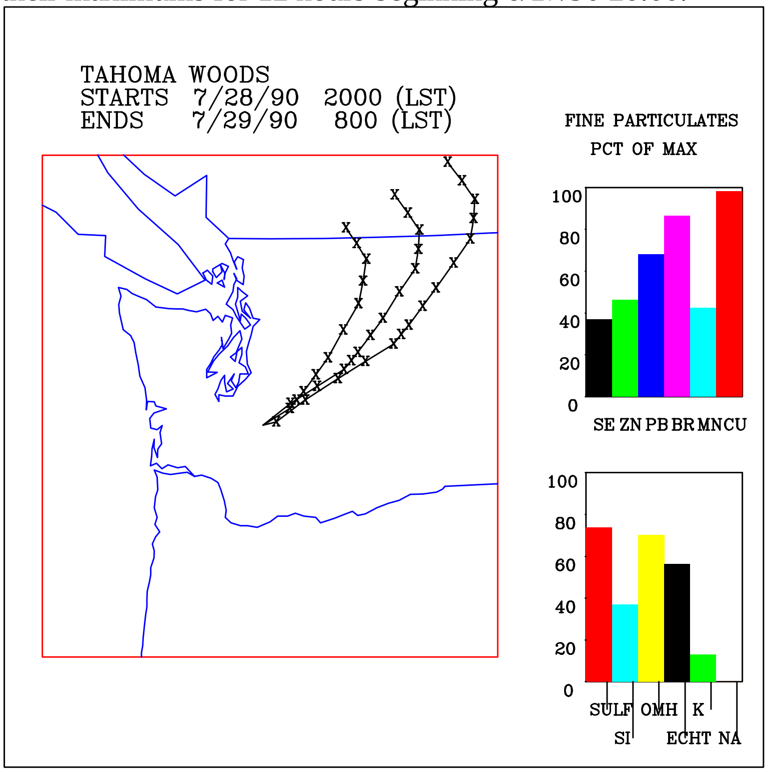

Figure 10-14. Back trajectories from Tahoma Woods and ratios of several particulate species to their maximums for 12 hours beginning 7/28/90 20:00.

10.3.1.2 Source Contribution Function

Residence time fields always have a peak at the receptor because all back trajectories originate there. The source contribution function is the residence time with this central tendency normalized out. It can be shown that the source contribution function is proportional to the residence time multiplied by the distance of the grid cell from the receptor. For relative comparisons between grid cells, the proportionality constant is irrelevant, and in most previous applications it has been set to $1/r_{max}$, where r_{max} is the maximum distance from the receptor to any trajectory endpoint.[2,3,4] However, the proportionality constant can be derived so that the source contribution function has a quantitative value for each grid cell.

The quantitative form of the overall source contribution function (OSC) is derived here. The high and low source contribution functions can be similarly derived. OSC is defined as:

$$OSC_{i,j} = \frac{ORT_{i,j}}{EPS_{i,j}} \quad \text{(10-2)}$$

where ORT is the overall residence time as defined by Equation 10-1 and EPS is an equal probability surface which is the probability that the endpoint would be in grid cell ***i,j*** if air arrived at constant speed with equal probability from all directions. The value of EPS for each grid cell is calculated by:

$$EPS_{i,j} = \frac{1}{r_{i,j}} \frac{A_{i,j}}{2\pi\, R_{norm}} \quad \text{(10-3)}$$

where $r_{i,j}$ is the distance from the receptor to the grid cell. The inverse distance factor results from the fact that all trajectories originate at the receptor. Thus a grid cell near the receptor is more likely to have an endpoint in it than a grid cell far away. $A_{i,j}$ is the area of the grid cell. In this grid system, which is based on degrees of latitude and longitude, each grid cell does not have the same area. Grid cells to the north are smaller than those to the south. Grid cell area in square kilometers is calculated by:

$$\begin{aligned} A_{i,j} &= \Delta X\ \Delta Y \\ &= (1/4\,{}^\circ Lat\,)^2\,(111.11\,Km/{}^\circ Lat\,)^2\ \mathrm{COS}(Lat). \end{aligned} \quad \text{(10-4)}$$

R_{norm} is the "normalization radius." This is the radius of the area in which the EPS integrates to one, so ($2\pi\ R_{norm}$) is the total area in which the EPS is defined. R_{norm} is somewhat arbitrary. It controls the slope of the EPS surface. Smaller values will result in an EPS with steeper sides. Because the EPS is zero beyond R_{norm}, OSC is undefined when $r_{i,j}$ is greater than R_{norm}. R_{norm} was calculated to keep the ratio of R_{norm} to the total number of endpoints equal to the ratio of the radius to total endpoints in the central nine grid cells. Thus R_{norm} is calculated by solving:

$$\frac{R_{norm}}{N} = \frac{R_{cent}}{N_{cent}} \tag{10-5}$$

where

$$N_{cent} = \sum_{i=iorg-1}^{iorg+1} \sum_{j=jorg-1}^{jorg+1} n_{i,j} \tag{10-6}$$

and *iorg* and *jorg* are the *i* and *j* coordinates of the grid cell containing the receptor (the origin). R_{cent} is calculated by solving for it in the following relationship.

$$\pi R_{cent}^2 = \sum_{i=iorg-1}^{iorg+1} \sum_{j=jorg-1}^{jorg+1} A_{i,j} \tag{10-7}$$

The functional equations for the overall, high concentration, and low concentration source contribution functions, obtained by combining Equations 10-1 through 10-3, are:

$$\begin{aligned} OSC_{i,j} &= \frac{2\pi R_{norm} r_{i,j}}{N A_{i,j}} \sum_{t=1}^{T} n_{i,j,t} \\ HSC_{i,j} &= \frac{2\pi R_{norm} r_{i,j}}{N A_{i,j}} \sum_{t=1}^{T} h_{i,j,t} \\ LSC_{i,j} &= \frac{2\pi R_{norm} r_{i,j}}{N A_{i,j}} \sum_{t=1}^{T} l_{i,j,t} \end{aligned} \tag{10-8}$$

10.3.1.3 Conditional Probability

Conditional probability is the probability that if the air mass passed through the grid cell, it arrived at the receptor when the concentration satisfied a given condition. The high concentration and low concentration conditional probabilities are calculated by:

$$\begin{aligned} HCP_{i,j} &= \sum_{t=1}^{T} h_{i,j,t} \Big/ \sum_{t=1}^{T} n_{i,j,t} \\ LCP_{i,j} &= \sum_{t=1}^{T} l_{i,j,t} \Big/ \sum_{t=1}^{T} n_{i,j,t} \end{aligned} \tag{10-9}$$

where all variables are as defined in Equation 10-1.

10.3.1.4 Low Confidence Flags

Grid cells which have few total endpoints are examined to determine the statistical significance of the high concentration conditional probability**.** If there are more than 50 total endpoints in the grid cell, the results are considered significant. If the cell has fewer than 50 total endpoints then the number of endpoints associated with the condition, the total number of endpoints, and the assumption of a binomial distribution are used to determine the upper and lower limits of the 90% confidence interval for the conditional probability. If the range of the upper and lower limits of the confidence interval is greater than 25% and the lower limit of the interval is less than 20% then the conditional probability for that grid cell is considered insignificant. If the interval is greater than 25% and the lower limit of the interval is greater than 20%, the value is labeled "suspect." Insignificant and suspect values are not plotted.

10.3.1.5 Determination of High and Low Concentrations

High and low values are defined to be values which are more than one geometric standard deviation above and below, respectively, the geometric mean concentration at the receptor. It is possible to have concentrations which are at or below the minimum detection limit. Because it is not possible to calculate the logs of these values, they were set to a small concentration, approximately 1/2 the minimum detection limit for that species. Table 10-3 shows the values used for each species.

Table 10-3.Value used in place of zero for the geometric means of each species.

Species	ng/m^3
S	1.
ECHT	100.
Na	5.
Se	0.1 (0.01 for XRF)
As	0.1 (0.01 for XRF)
Cu	0.1
Pb	0.5
Br	0.1
K	0.1
Mn	0.1
Si	1.0

Use of a standard deviation to determine the limits for the high and low concentrations is reasonable if the data are log-normally distributed. This is true for some species, such as sulfur. Other species such as carbons may have bimodal distributions.[4] However, for this analysis, the criteria are not changed. The geometric means and the values above and below which concentrations were considered to be high and low, respectively, are shown in Table 10-1.

10.3.1.6 Maximum and Average Concentration Maps

The maximum concentration maps show for each grid cell, the maximum concentration at the receptor associated with any of the trajectories which passed through that cell. Similarly, the average concentration maps show the average concentration at the receptor for all trajectories which passed through that cell.

10.3.2 Results

The maps which graphically depict the following results are in Appendix 9.

10.3.2.1 Overall Residence Times

The overall residence times are the same for all species for a given site. Furthermore, ORT results are similar for each of the three PREVENT receptor sites. The predominant pathways for air masses arriving at all sites are northwesterly and southwesterly, with northwesterly being the most common. Paradise appears to be slightly more likely than the other two sites to receive air masses from the northeast. However, results for Paradise may be different from the other two sites only because the length of the data record is much shorter. It is extremely unlikely for any of the three sites to be influenced by air masses arriving from the southeast.

10.3.2.2 Overall Source Contribution Functions

OSC results are also the same for each species for a given site. Results for all of the receptor sites are similar. Air is 500 to 1200% more likely to arrive from Vancouver Island and from an area in the Pacific Ocean west of Oregon than would be expected based on an equal probability surface. Air is less than 10% as likely to arrive from the southeast as would be expected if air arrived from all directions with equal probability.

10.3.2.3 Sulfur

Similar to the OSC, the HSC for sulfur shows pathways associated with high sulfur concentrations at Tahoma Woods extending to the receptor from the northwest and southwest. However, the HSC also shows a third pathway associated with high sulfur concentrations arriving from the northeast. The LSC indicates that air masses arriving from the Pacific Ocean are generally associated with low sulfur concentrations.

The conditional probabilities show that if air masses arrive from areas in the most densely populated corridor from stretching from Canada to Portland, they are likely to be associated with high sulfur concentrations at all three sites. Conversely, if air masses arrive from the west or

southwest (over the ocean) and from some parts of Canada they are most likely to be associated with low sulfur concentrations.

The highest average sulfur concentrations are associated with trajectories from the west for Paradise, and from the northeast for Tahoma Woods and Marblemount. The highest maximum concentrations are associated with transport from the west, north and northeast for Paradise, from the northeast, north, and southwest for Tahoma Woods, and from the northeast and northwest for Marblemount.

It is possible for air arriving from a single quadrant, i.e. southwest, to be associated both with high and low concentrations. For example, on one day air masses arriving at Tahoma Woods from the southwest may pass over only clean areas such as the ocean and arrive with low concentrations. While on another day, when the trajectory has a slightly different track, the air mass also passes over Tacoma or Centralia before arriving at the receptor and arrives with higher concentrations. The entire length of each back trajectory is associated with only one concentration even though it may pass over areas with both high and low emission densities. This is why some grid squares in the ocean (i.e. HCP for sulfur at Paradise) have relatively high probabilities of being associated with high concentrations, even though there are no emissions there. Other factors such as rainfall along the pathway or changes in emission rates of sources also influence whether or not the sulfur concentration in a given air mass is high or low.

Also note the differences between HSC and HCP maps. HCP is the probability that if the air mass resided in that grid cell, then the concentration at the receptor was high when it arrived. Air masses may very rarely arrive from that cell, but when they do the probability of a high concentration is high. HSC, on the other hand, show where the air most often arrived from when the concentration was high.

10.3.2.4 ECHT

The highest ECHT concentrations at Tahoma Woods and Paradise were associated with transport of air masses from the northeast. The highest likelihood of low ECHT concentrations at these two sites is when air masses arrive from the southwest or west across the Pacific Ocean. The maximum concentration maps also indicate that some high ECHT concentrations are associated with transport from the south, perhaps from Oregon. Results are similar for Marblemount, except that air arriving from the northwest is also associated with high ECHT concentrations.

10.3.2.5 Sodium

High sodium concentrations at Tahoma Woods are primarily associated with transport from the northwest across Vancouver Island, and secondarily with transport from due west. Low concentrations are associated mostly with transport from the east.

High concentrations at Paradise are also associated with transport from the northwest. Air masses arriving from the north can arrive at Paradise with either high or low sodium, although the pathway associated with high sodium is farther east.

High sodium concentrations at Marblemount are associated with transport from the northwest and west. Air masses arriving at Marblemount from the north and northeast are the most likely to be associated with low sodium concentrations.

10.3.2.6 Silicon

In general high silicon concentrations at all three sites occurred when air masses arrived from the north, and low concentrations occurred when air masses arrived from farther south.

10.3.2.7 Potassium

At all three sites there were a small number of observations with concentrations much higher than the remaining time periods at that site. These time periods at all sites were associated with trajectories which passed through the northwest corner of Oregon (see maps of maximum concentration). Air masses arriving at all sites from the northeast were also associated with potassium concentrations which were more than one standard deviation above the mean.

10.3.2.8 Lead

Lead concentration data obtained from PIXE analysis were used for Marblemount, while data obtained by the higher sensitivity XRF analysis were available and were used for Tahoma Woods and Paradise. At Marblemount there were two time periods with lead concentrations greater than 50 ng/m^3. Concentrations during all other time periods were less than 10 ng/m^3. A similar "spiky" pattern was not observed at the other two sites, so these two high values at Marblemount may be due to a problem with the PIXE analysis. All lead concentrations except one at Tahoma Woods and Paradise were less than 10 ng/m^3.

High lead concentrations at Tahoma Woods and Paradise were associated mostly with transport from the northwest and north. However, the highest concentrations at both sites were associated with a pathway which runs northeast and southwest. Low lead concentrations at these two sites were associated with air masses from the west and south.

High lead at Marblemount arrives with air masses which have passed over the Seattle-Tacoma urban corridor.

10.3.2.9 Bromine

As for lead, data from the XRF analysis were used for Tahoma Woods and Paradise while PIXE data were used for Marblemount. However, unlike the lead concentrations, the bromine values at Marblemount appear to be reasonable.

High bromine concentrations appear to be associated with air masses arriving from the north, while low concentrations are associated with air masses from the south. Similar patterns are observed for all three sites.

10.3.2.10 Selenium

Selenium concentrations based on XRF analysis were used for Tahoma Woods and Paradise. Only PIXE data were available for Marblemount and the PIXE Se concentrations were mostly below detection limit. Therefore, no trajectory analysis was conducted for selenium at Marblemount.

Air masses arriving at Tahoma Woods and Paradise after passing over Centralia are associated with high selenium concentrations. Another pathway to the northeast is also associated with high selenium. The highest probability of low concentrations at both sites is when air arrives from the southwest.

10.4 SUMMARY

Analyses of the air mass back trajectories which arrived at the receptor sites during PREVENT suggest that:

1. The predominant wind patterns in the study area are most likely to bring air masses from the northwest and southwest to the receptor sites. Winds from the southeast are the least frequent.

2. Emissions from Centralia Power Plant are very likely to have reached Marblemount during 9% of the 12-hour duration monitoring periods, Tahoma Woods during 27% of the time periods, and Paradise during 15% of the time periods.

3. High sulfur and selenium concentrations are associated not only with transport from Centralia, but also with transport from the south, perhaps Portland, OR, and from the northeast, perhaps Calgary or another source region in Canada.

4. Air masses arriving from the southwest (across the Pacific Ocean), as expected, arrive when the sulfur concentrations are low.

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