"Summer Haze in Japan: A Chinese Source?"

Professor Thomas A. Cahill,
Atmospheric Sciences/Physics and Director, DELTA Group,
University of California, Davis CA 95616 USA
and
Prof. Mikio Kasahara,
Director, Graduate Group in Energy and the Environment, U. Kyoto, Uji, Japan

I want to express my deep appreciation to Prof. Masahisa Ohta, for the invitation to present some of our research results to you here at Konan University, Kobe.
I have had many years of fruitful collaboration with scientists in Japan, first with Dr. Matsuda, then with Prof. Hiro Miyake of Kobe and most recently with Prof. Mikio
Kasahara in Kyoto. This work in Japan has now become my major effort, due to the critical role Asia now plays in the issue of global climate change. Again, thank you all for this opportunity.

The story begins in Hawaii, at the Mauna Loa Observatory (MLO) of the National Oceanic and Atmospheric Administration. This laboratory is located high atop Mauna
Loa Volcano on the island of Hawaii, at an elevation of 3140 m and in the middle of the Pacific Ocean. This site was chosen 40 years ago as the site most remote from industrial sources of pollution in the Northern hemisphere. It was this laboratory that first detected that the background level of carbon dioxide (CO_2) was rising, a result now confirmed all over the world. There is no controversy about this change. It is real. It is big, now amounting to an increase of about 30%. Controversy exists over the nature of its impact on the world, but none exists about the fact that we are dramatically changing the very air we breathe.

Figure 1: The trend of CO_2 at Mauna Loa for the past 40 years

But is MLO really a remote, clean site? For many years, MLO was known to impacted each Spring by dust in the famous "kosa" events. Figure 2 shows this pattern
for the past decade or so, in measurements made by Prof. Perry and I as part of a

study of visibility at US national parks. But people tended to ignore this dust as being "desert dust" and natural in origin.

Figure 2: The impact of "kosa" dust at Mauna Loa for the past 10 years

We used proton induced x-ray emission (PIXE) and x-ray fluorescence (XRF) to examine these periods, and found to our surprise that the "kosa" events had all the elemental signatures of pollution from copper smelters.

Figure 3: Pattern of trace elements in a "kosa" event.

Table 1: Comparison of trace elements in a "kosa" event to copper smelters in the United States.

But most of the copper smelters upwind were in Manchuria, although Japan has some, too. Thus, we made detailed measurements in 1996 that just appeared in an article by Perry et al (1999). In it, we examine the man made pollution at Mauna Loa, and find that it is dominated by northern Asia sources. Figure 4 shows the monthly average
contribution.

Figure 4: Pollutants at Mauna Loa Observatory, annual average (a)

Figure 5: Pollutants at Mauna Loa Observatory, annual average (b)

But there was a surprise. There is as much organic matter (mostly smoke) and sulfates (mostly coal fired power plants) as there is dust. The "kosa" events were just a part of a period of many months with efficient transport from Asia into the Pacific.

But we can do much better than that. Examining transport during a "kosa" period in detail, using PIXE and continuous strip samplers, we can follow dust and man made
pollutants hour by hour. Figure 6 shows the "kosa" dust, but also sulfates, smoke, and soot.

Figure 6: Strip sample from a DRUM impactor, May, 1996.

Now we can use wind patterns to create "trajectories" that go back to sources. Figure 7 shows trajectories to Mauna Loa during that period. Note that the "kosa" events, with smelter metals such as arsenic, zinc, copper, and lead, go right to Manchuria after passing over Japan.

Figure 7: Trajectories in the Pacific, May, 1996.

The smoke and most of the sulfates, on the other hand, come from central China.

But do these materials stop at Hawaii? Not at all. They fill the entire North Pacific basin, as shown by a "kosa" event seen at Crater Lake National Park, Oregon, April - May, 1998.

Figure 8: Asian aerosols at Crater Lake NP, Oregon

This is not a small event. For 5 days, this event, with its arsenic and all, dominated the entire western United States.

Figure 9: Impact of the May, 1998 "kosa" event on the western United States.

In fact, the event came close to violating US Environmental Protection Agency health guidelines for particles based on dust from Asia. It would have been previously
unthinkable to have a Japanese tourist at Yellowstone NP, Wyoming, have his pictures
blurred because of dust from China! It just proves that this is a small world after all.

Recall Figure 5 for a moment. Note that in June, the air at Mauna Loa Observatory cleans up. The soil is long gone, but now the organic aerosols and sulfates also go away. Is this because the source has turned off? No. It is because in late June and July, the westerly air flows that bring these materials to Hawaii change, and winds in central China blow to the northeast, in fact, towards Japan. So, if aerosols from China can even pollute Yellowstone NP in Wyoming, to say nothing of haze in Hawaii, what is the impact on Japan, so much closer to the source?

In summer, 1992, I began a long term collaboration with Prof. Kasahara and the University of Kyoto by sampling aerosols at the Uji campus. We were trying to understand more about the intense summer hazes in Japan, hazes that appeared mysterious based on my US based experience. The hazes were very intense, but had the wrong color for sulfate, nitrate, and soot hazes all too common in the United States (yes, even in California!). Also, Japan had made major reductions in sulfates, but the hazes persisted. Could this be from a source outside of Japan? We thought that a good part of the haze in Japan might not come from local sources. First, the hazes extend over the entire nation, and including areas with little pollution. Second, the hazes extend to high elevation well above Mt. Fuji. Normally, it takes time and space to have pollutants rise that high. But unlike California, which has a relatively clean ocean upwind, Japan is downwind of mainland Asia.

At this point, let me digress to talk about what causes a haze. Haze or degraded visibility is normally caused by very fine particles in the air.

Figure 10: Physics of haze

Here is the physics of the situation. If the particles are too small, less than the wavelength of light at 0.5 to 0.7 micrometers, they ride light waves like a cork rides an ocean wave. No ripples result, even if there are lots of particles. Big particles, much larger than the wavelength of light, are too few to have much effect since for constant mass, the number goes down as their radius is cubed. On the other hand, particles near or above the wavelength of light, namely from 0.3 to 1 micrometer in diameter (an average human hair is about 200 micrometers diameter), thrash around on a light wave like a log in ocean waves, with lots of ripples. These ripples are haze, scattered sunlight, making the scene both bluish and blurry and limiting how far you can see. This is also why most cameras use a "skylight" filter to reduce haze effects.

To examine the haze, we set up air samplers at the Uji campus in summer 1992. We then sampled for two consecutive weeks, starting at the tail end of 3 weeks of bad visibility. The data were interrupted by parts of two typhoons. What we found was surprising. First, the pollutants we associate with bad visibility in the USA were absent.

Sulfates were low, there was no soil, and even soot was minor. Figure 11 shows the pollutants we measured in this period. In the middle, Typhoon Irving cleared out all pollutants, (Figure 12), and the haze never was as bad again in the sampling period.

Figure 11: Fine particles at Uji, summer, 1992.

Figure 12: Meteorological conditions, August 6, 1992.

Note that during the July period, after the rainy season, the wind flow tends to be from the southwest, pushing pollutants from central China towards Japan. Compare this with the spring "kosa" period, when the wind is from the west and north west, from the Chinese and Mongolian deserts over Manchuria and into Japan.

Figure 13: Seasonal winds in north Asia

What we found were organic particles, coarse organic particles unlike those seen before. Remember, this was a time before we understood the major impacts at Mauna
Loa Observatory or Crater Lake NP. Figure 15 shows the size distribution of the organic matter, a spectrum unlike any we had ever seen. Note that not only was there a lot of organics (probably mostly smoke), but their size was optimum for causing haze.

Figure 14: Haze particles, giving bad visibility at the beginning of the study.

A few days later, the visibility improved slightly, and the spectrum shifted to a haze dominated by fine sulfates. (Figure 15) Again, there was negligible soil.

Figure 15: Haze particles, middle of the study.

After the typhoon, the pattern became a typical pattern with some smoke and some sulfate haze, but never re-established the serious haze episode of July.

Figure 16: Haze particles, good visibility towards the end of the study.

We never published these data, partly because we did not understand the significance of what we had done. We also hesitated because these were new techniques, never before tried. We were not sure that we were fooling ourselves. Since that time, we have used the same techniques in major international experiments, and have the quality assurance and confidence to know that the pioneering efforts of summer, 1992, were in fact sound. We also understand now that it is not just "kosa" dust from North Asia that fills the North Pacific each Spring, but also organic and sulfate hazes from middle latitudes especially China, but also including smoke from forest burning further south in Indonesia and Borneo, as well as Mexico.

Thus, we are lead to conclude that the bad summer hazes in Japan in summer are part of a much larger pattern, one that is capable of modifying the climate of the Earth. Going back to the first figure, we now know that the cleanest place in the northern hemisphere, the north Pacific, is highly polluted for 6 months of each year, modifying sunlight and climate with uncertain but troubling effects.

What are we to do about this?

First, this is only a hypothesis, and we must prove it before we can act on it as fact. We will start sampling air routinely at Uji and at Cheju Island, Korea, this winter, in anticipation of the Spring "kosa" events and the summer hazes. This work is funded by the University of California in its Pacific Rim research program. We will compare aerosols coming into Cheju Island with those in Uji. From the difference when wind blows from Cheju to Uji, we can find the contribution of the Kansai region to Uji aerosols. These data will be combined with Kyoto University's growing expertise in atmospheric optics to predict and measure each component of the haze.

Next, there is a major international program called "ACE-Asia," for Aerosol Characterization Experiment - Asia, scheduled for Spring, 2001. This is a 12 coun-
try
program to understand the effect of Asia, all of Asia, on global climate.

Figure 17: ACE-Asia prospectus

Japan is a major player in this effort, with many universities, ships and planes, ground station and satellite data contributing to the study. But funds are always tight, and we have many hurdles to overcome to make this study the definitive effort we all need. It is very important that we do our work well, and soon. Table 2 shows the present contribution of various countries around the world to one of the most important Greenhouse aerosols, sulfates, derived from SO2 emissions.

Table 2: Contributions to global SO2 emissions

The role of the coal rich countries, China and India, are all too clear, and the future impact all too ominous. If l had similar data for CO2, it would be the United States that is the major polluter, but with China a close second and rising rapidly.

Japan today may well be in the same position of Scandinavia in the 1950s. Scandinavian countries, especially Sweden, alerted Europe to the transport of pollutants into the Scandinavian lakes and streams, killing fish and forests with acidic rainfall. Japan is in a similar position in northeast Asia. As it cleans up its own pollutants, it will more and more be subject to the success or failure of pollutant efforts upwind, especially China and Korea. There will have to be a great deal of multinational cooperation in achieving the mutual goal of clean air, for there is no doubt that dirty air in China hurts the Chinese much more than it hurts the Japanese. Recent data (Kunming, Nov, 1999) shows that agricultural production in much of the Chinese heartland is decreased about 20% by the persistent summer haze that blocks the sun, and our own data from California predict a serious shortening of life span due to hearts weakened by fine particles.

What examples can we present of future success? In the United States, we too had an awful haze and acid rain problem from the 1970s on, as we burned more and more
coal to power our air conditioners each summer. We too had visibility as low as a few kilometers over much of the eastern United States. I was proud to work with the National Park Service, and our data helped to pass a major law restricting sulfur emissions, the Clean Air Act of 1991. This mandated a reduction of 10 million tons of sulfur/year, or about 1/2 ofthe US total, by 2006. It also gave industry great flexibility on how to achieve this goal. How are we doing?

We are well ahead of schedule, and at asmall percentage of the anticipated costs. Already, the air in New England is getting visibly better, and more improvement will follow. In the western United states, we have already seen improvements of 35% in air quality and visibility in Colorado national parks, and more will soon come once sulfur scrubbers are installed on the last two uncontrolled coal fired power plants, which happen to be at both ends of the Grand Canyon. -

Figure 18: Victory in the Grand Canyon!

This can work in Asia, with Japanese technology assisting other countries to clean up their old, sometimes Russian-designed, power plants. These plants waste a large fraction of the coal they burn, costing China resources, increasing costs, and pollut-ing the air, all at the same time! There must be an effort at controlling bio-mass burning, vehicles, etc. The first to benefit will be the local citizens, reflected in better air quality in Japan.

We now more than ever realize that we live in a small world. We can make the skies blue again, reduce disease, increase agricultural production, stabilize and then reverse global warming. I am pleased to have the opportunity to work with Japan in this vital project.

Thank you very much for this opportunity.

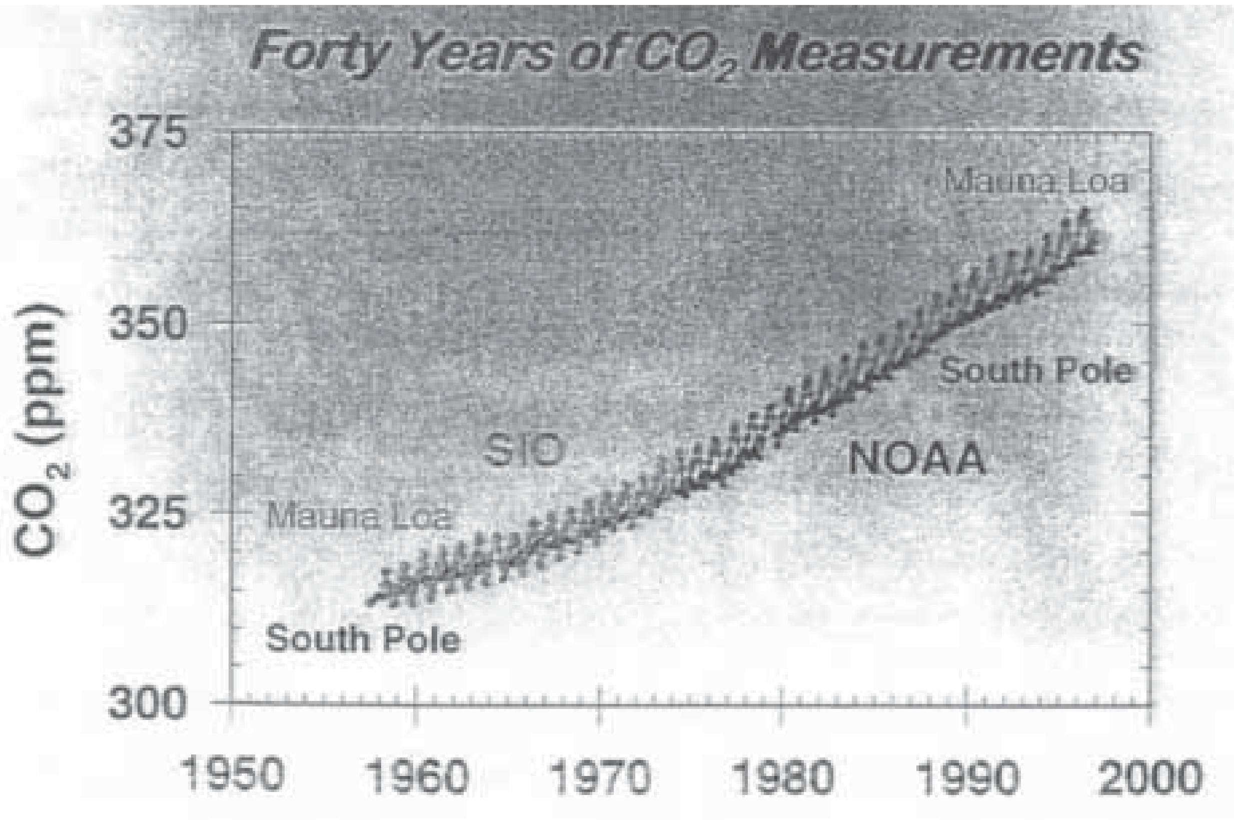

Forty Years of CO_2 Measurements
CO_2 (ppm)
375
350
325
300
Mauna Loa
South Pole
SIO
NOAA
Mauna Loa
South Pole
1950
1960
1970
1980
1990
2000

fig.1

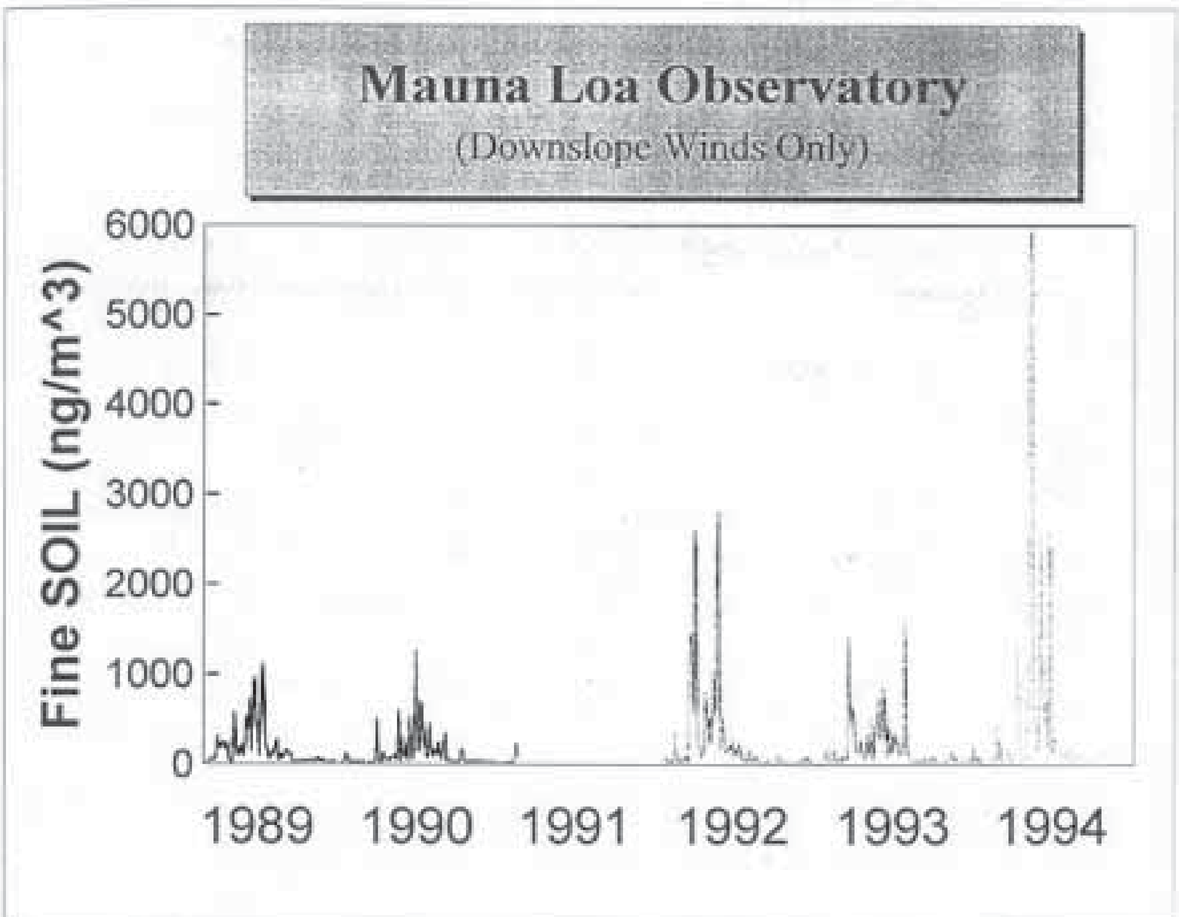

Mauna Loa Observatory
(Downslope Winds Only)
Fine SOIL (ng/m^3)
6000
5000
4000
3000
2000
1000
0
1989
1990
1991
1992
1993
1994

fig.2

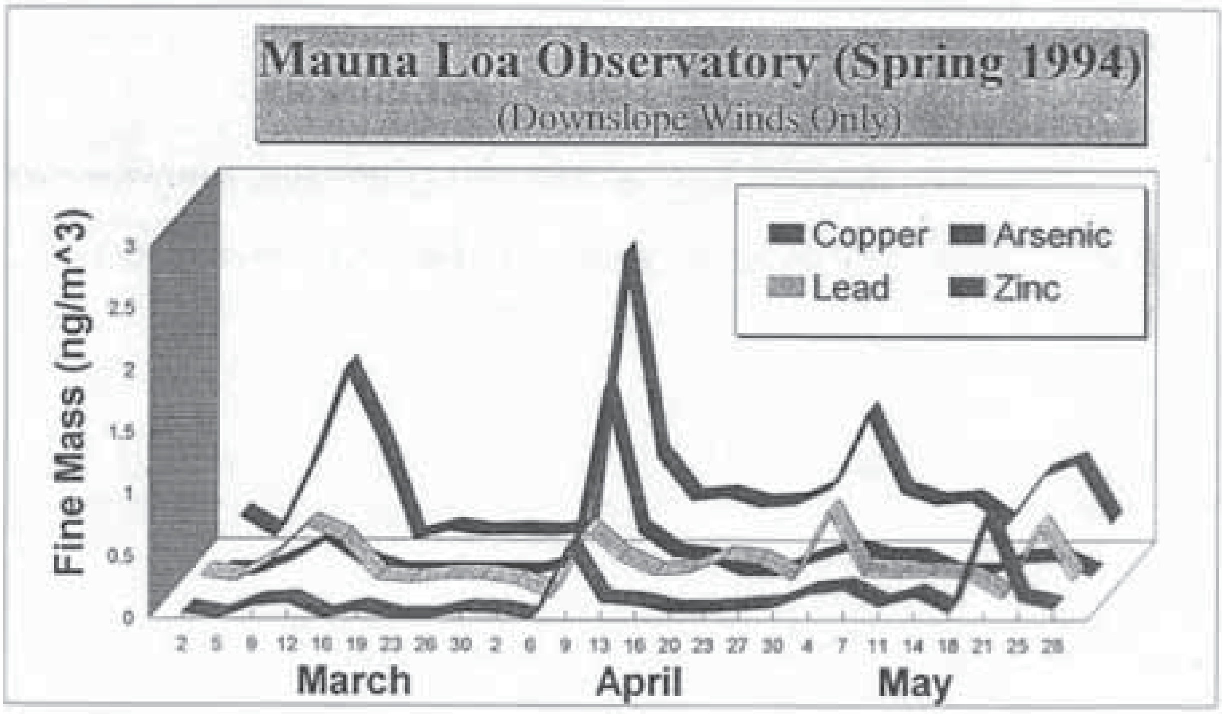


fig.3

COMPARISON TO POTENTIAL					
	SO4=	Se	Cu	Zn	As
1. VOLCANOES					
Kiluaea (11/21/92)	10	19	3.9	3.7	0.32
2. COPPER SMELTERS*					
Average (All)	10	17	200	280	60
Smelter #5 Ajo, Az (morm. to S)					
3. MAUNA LOA (down)					
April 9, 1994	10	<0.7	10	36	23
Trace elements in ng/m3; Sulfate in ug/m3					
*Small et al, ES&T 15, 293-299 (1981)					

Table 1

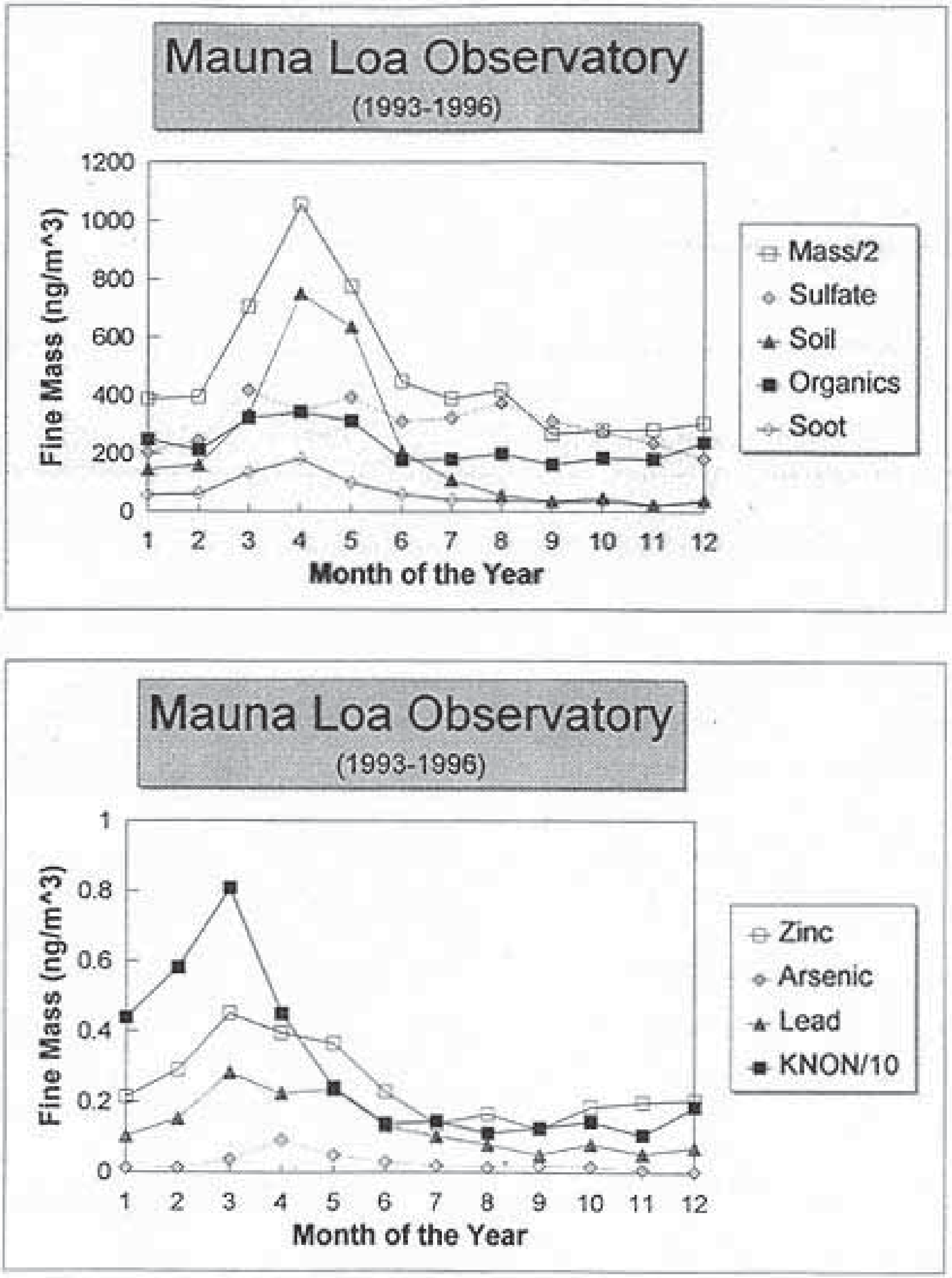

Mauna Loa Observatory
(1993-1996)
Fine Mass (ng/m^3)
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12
Month of the Year
Mass/2
Sulfate
Soil
Organics
Soot
Mauna Loa Observatory
(1993-1996)
Fine Mass (ng/m^3)
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12
Month of the Year
Zinc
Arsenic
Lead
KNON/10

fig.4

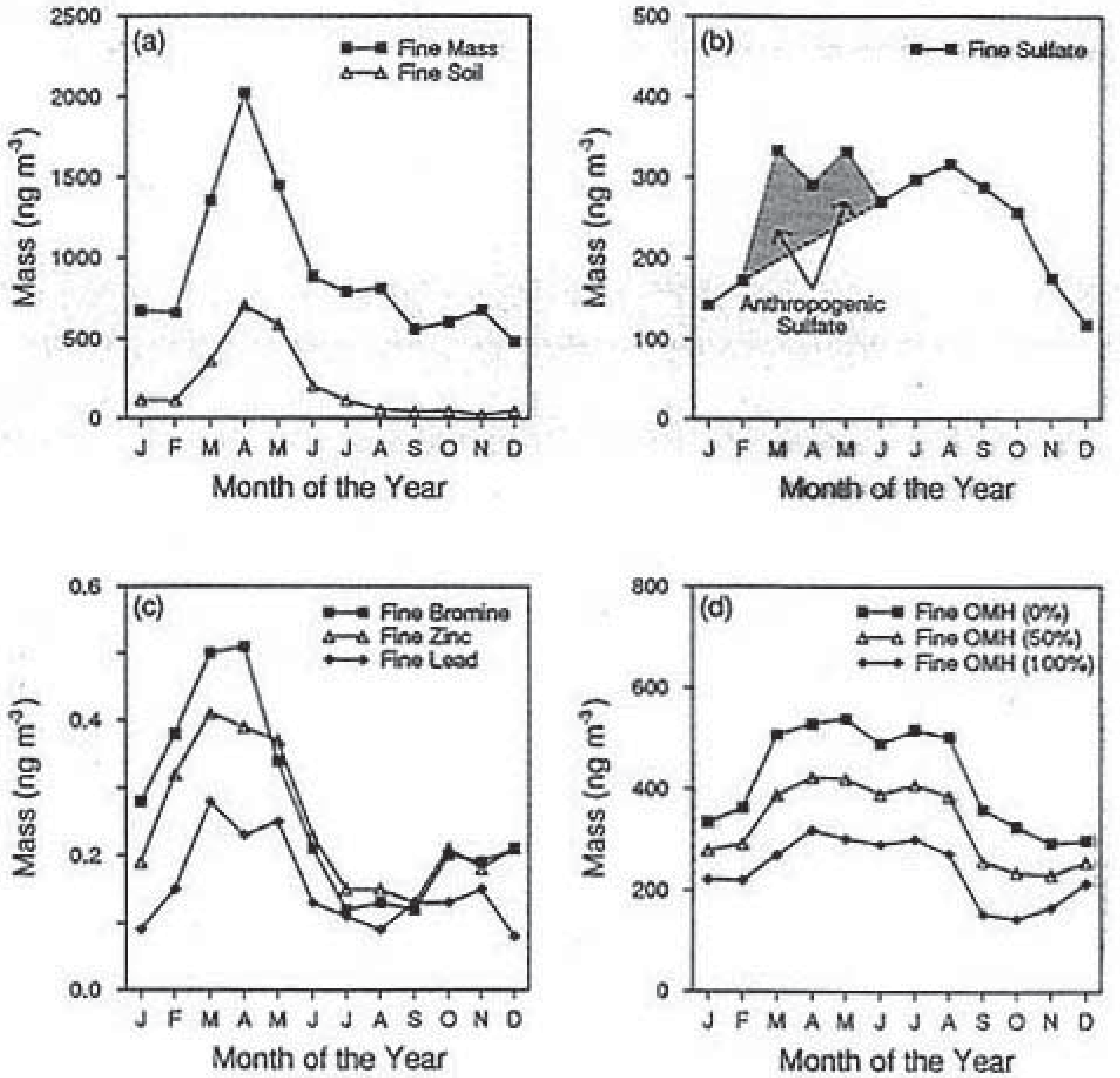
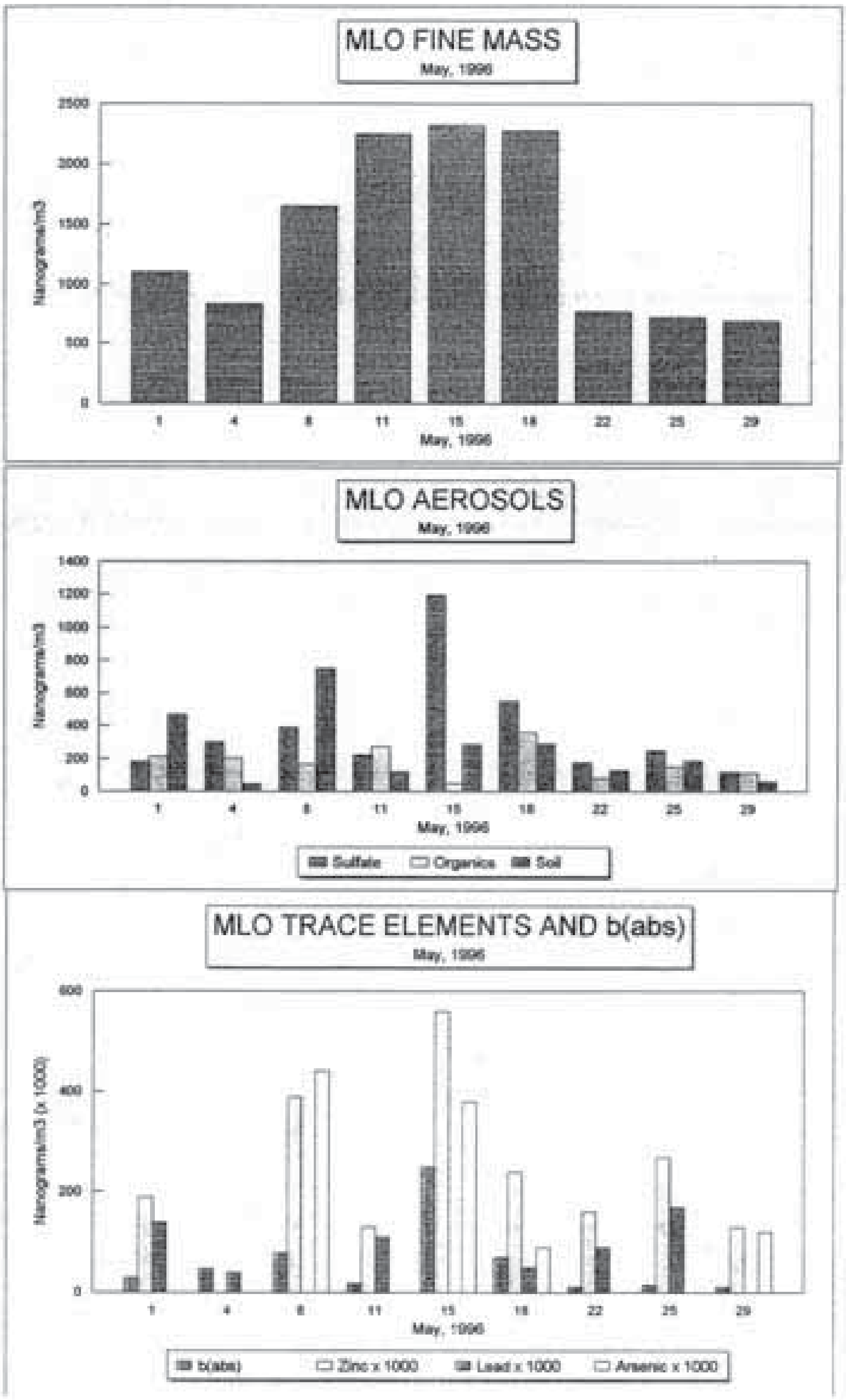

(a)
Fine Mass
Fine Soil
Mass (ng m-3)
Month of the Year
(b)
Fine Sulfate
Anthropogenic Sulfate
Mass (ng m-3)
Month of the Year
(c)
Fine Bromine
Fine Zinc
Fine Lead
Mass (ng m-3)
Month of the Year
(d)
Fine OMH (0%)
Fine OMH (50%)
Fine OMH (100%)
Mass (ng m-3)
Month of the Year

fig.5



MLO FINE MASS
May, 1996
Nanograms/m3
May, 1996
MLO AEROSOLS
May, 1996
Nanograms/m3
May, 1996
Sulfate
Organics
Soil
MLO TRACE ELEMENTS AND b(abs)
May, 1996
Nanograms/m3 (x 1000)
May, 1996
b(abs)
Zinc x 1000
Lead x 1000
Arsenic x 1000

fig.6

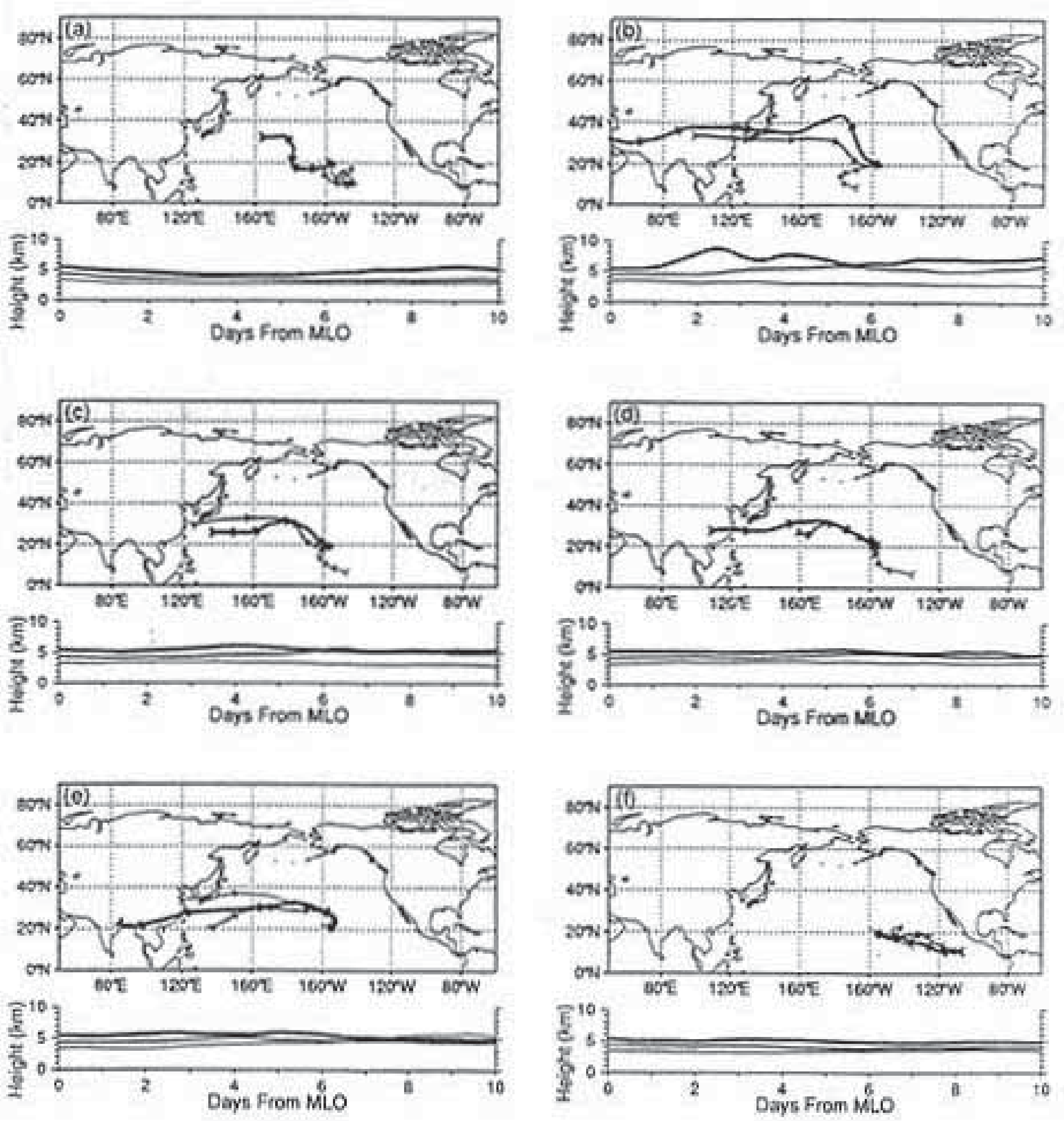

(a)
(b)
(c)
(d)
(e)
(f)
80°N
60°N
40°N
20°N
0°N
80°E
120°E
160°E
160°W
120°W
80°W
Height (km)
Days From MLO

fig.7

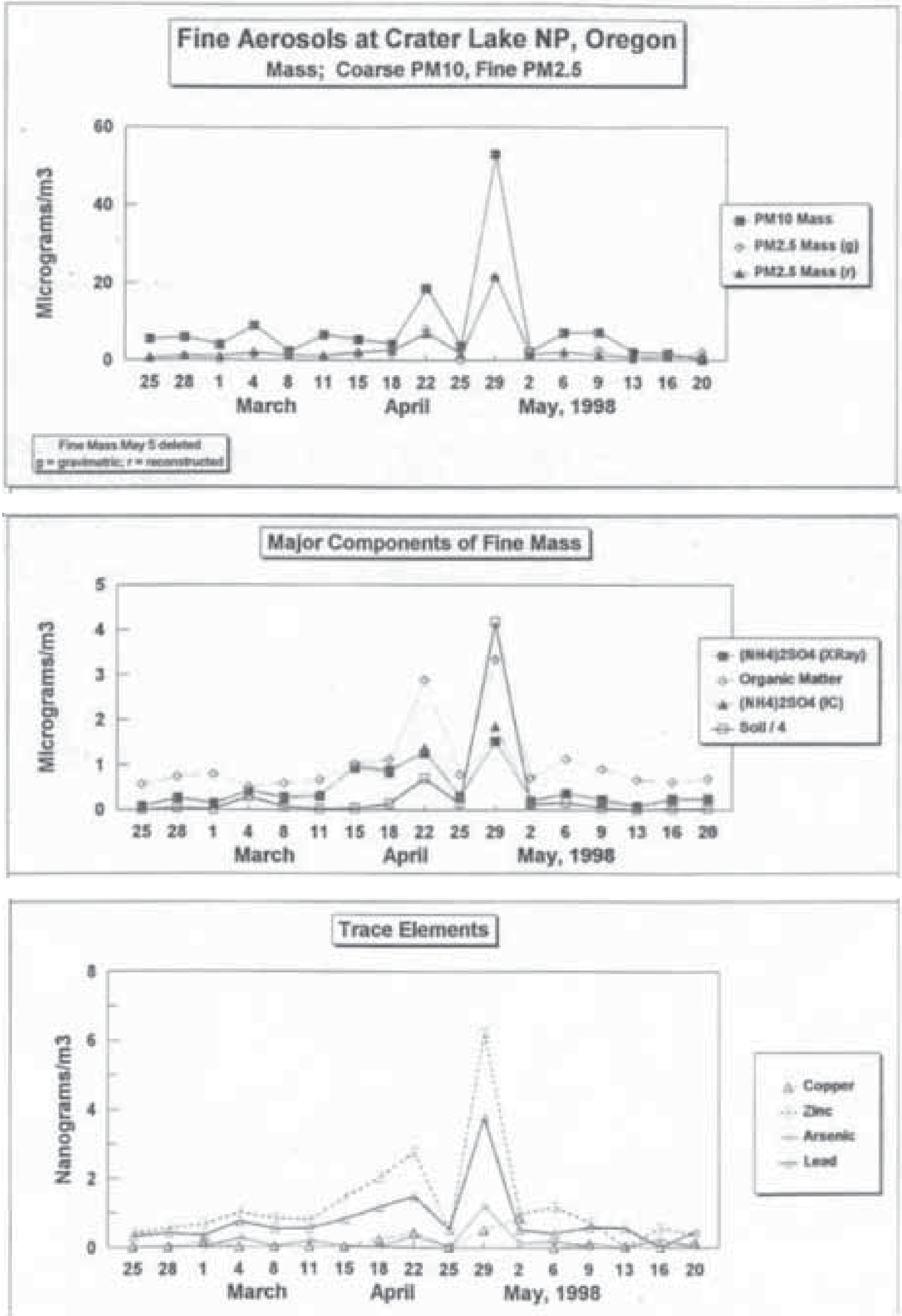

Fine Aerosols at Crater Lake NP, Oregon
Mass; Coarse PM10, Fine PM2.5
Micrograms/m3
60
40
20
0
PM10 Mass
PM2.5 Mass (g)
PM2.5 Mass (r)
25 28 1 4 8 11 15 18 22 25 29 2 6 9 13 16 20
March
April
May, 1998
Fine Mass May 5 deleted
g = gravimetric; r = reconstructed
Major Components of Fine Mass
Micrograms/m3
5
4
3
2
1
0
(NH4)2SO4 (XRay)
Organic Matter
(NH4)2SO4 (IC)
Soil / 4
25 28 1 4 8 11 15 18 22 25 29 2 6 9 13 16 20
March
April
May, 1998
Trace Elements
Nanograms/m3
8
6
4
2
0
Copper
Zinc
Arsenic
Lead
25 28 1 4 8 11 15 18 22 25 29 2 6 9 13 16 20
March
April
May, 1998

fig.8

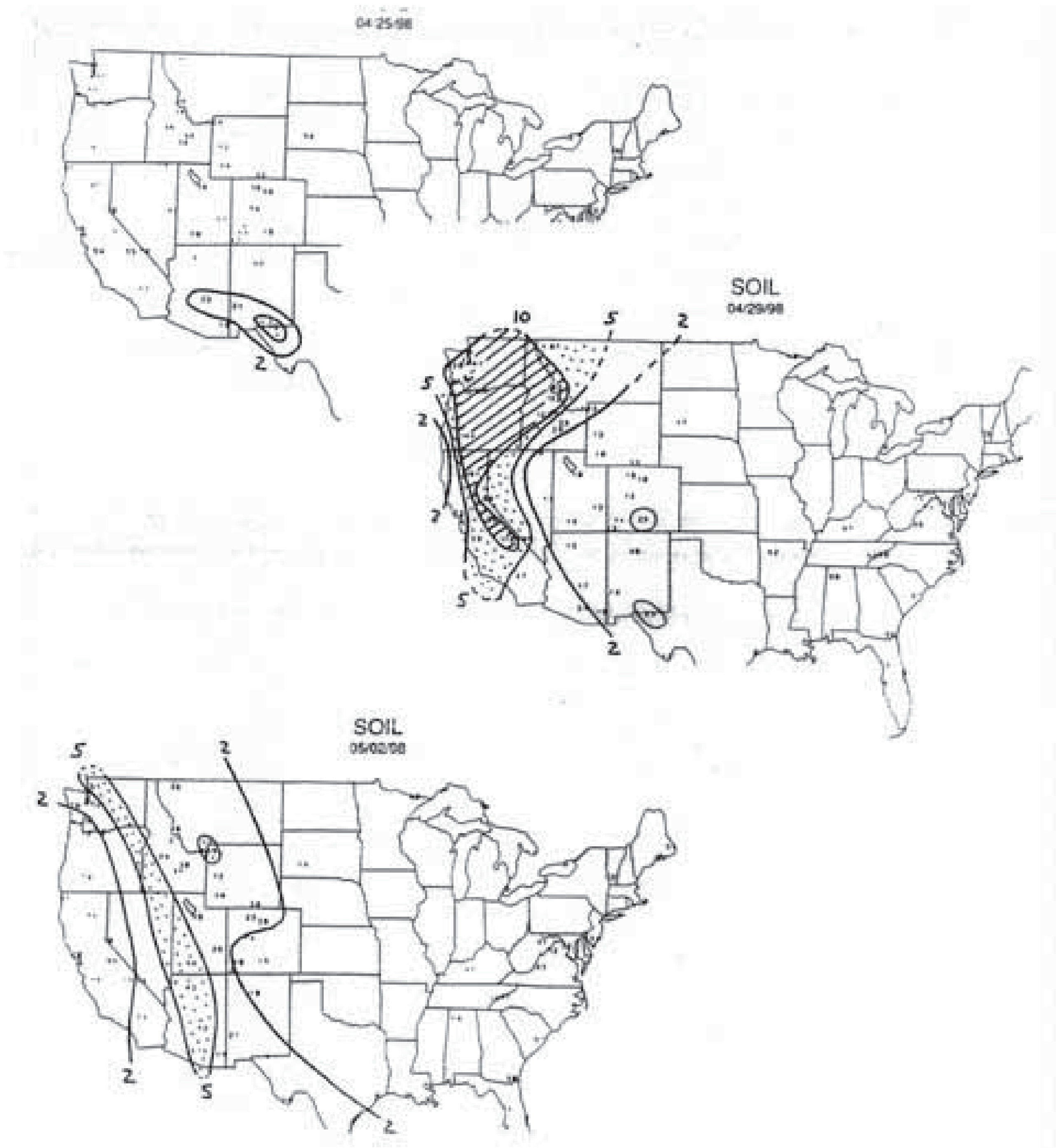


fig.9

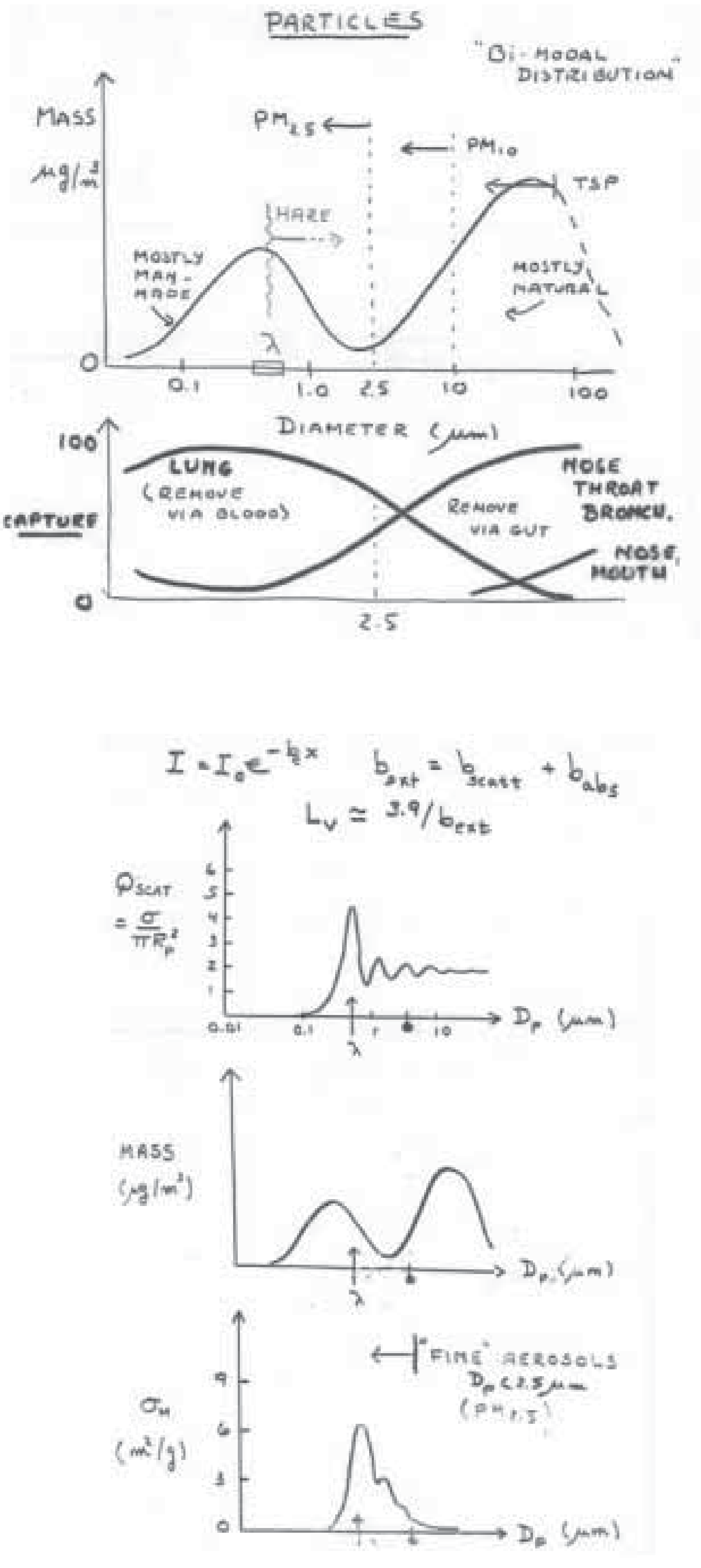

PARTICLES
"Bi-MODAL DISTRIBUTION"
MASS
µg/m³
PM2.5
PM10
TSP
HAZE
MOSTLY MAN-MADE
MOSTLY NATURAL
λ
0
0.1
1.0
2.5
10
100
DIAMETER (µm)
100
CAPTURE
LUNG (REMOVE VIA BLOOD)
REMOVE VIA GUT
NOSE THROAT BRONCH.
NOSE, MOUTH
2.5
I = I₀e^(−bx)
b_ext = b_scatt + b_abs
L_V ≃ 3.9/b_ext
Q_SCAT = σ/πR_p²
Dp (µm)
MASS (µg/m³)
σ_M (m²/g)
"FINE" AEROSOLS
Dp < 2.5 µm
(PM2.5)

fig.10

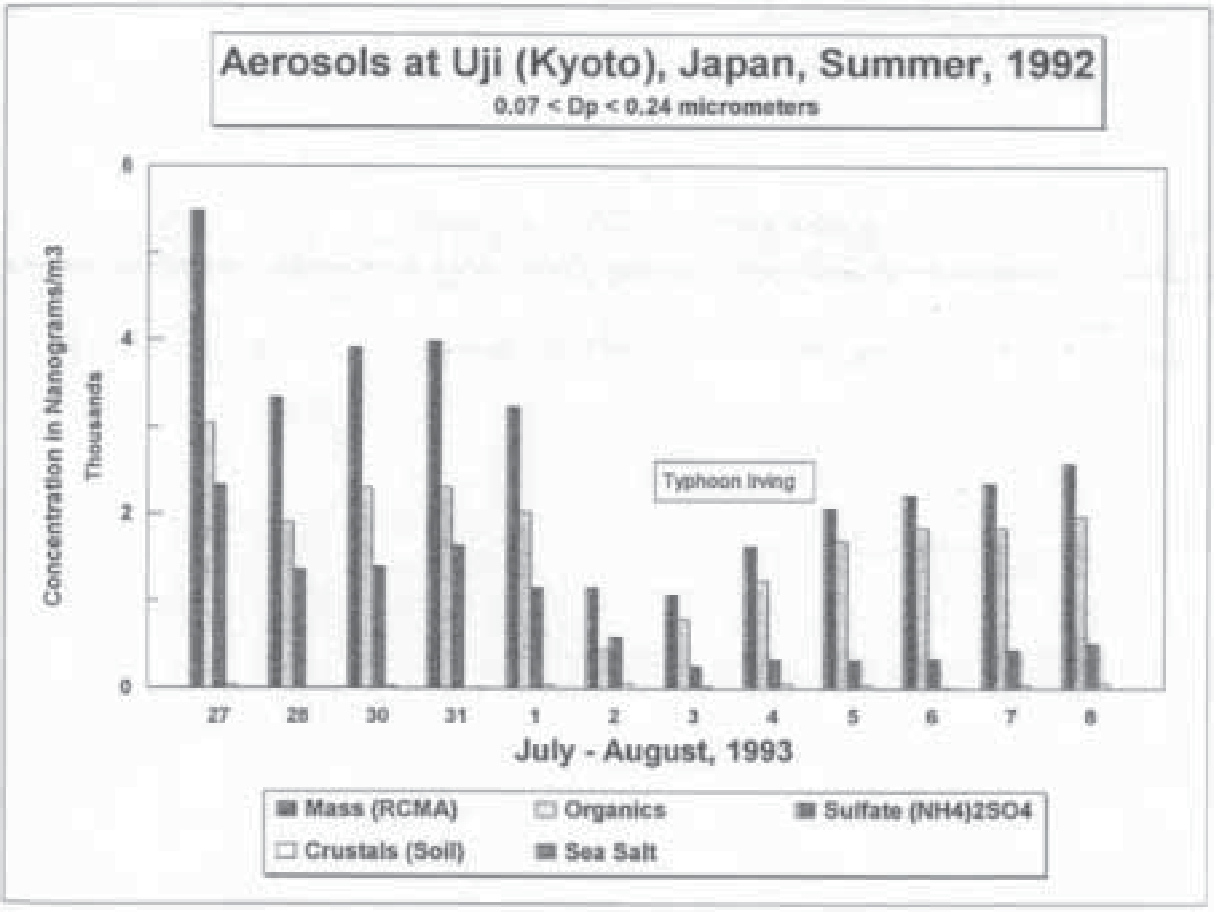

Aerosols at Uji (Kyoto), Japan, Summer, 1992
0.07 < Dp < 0.24 micrometers
Concentration in Nanograms/m3
Thousands
6
4
2
0
Typhoon Irving
27
28
30
31
1
2
3
4
5
6
7
8
July - August, 1993
Mass (RCMA)
Organics
Sulfate (NH4)2SO4
Crustals (Soil)
Sea Salt

fig.11

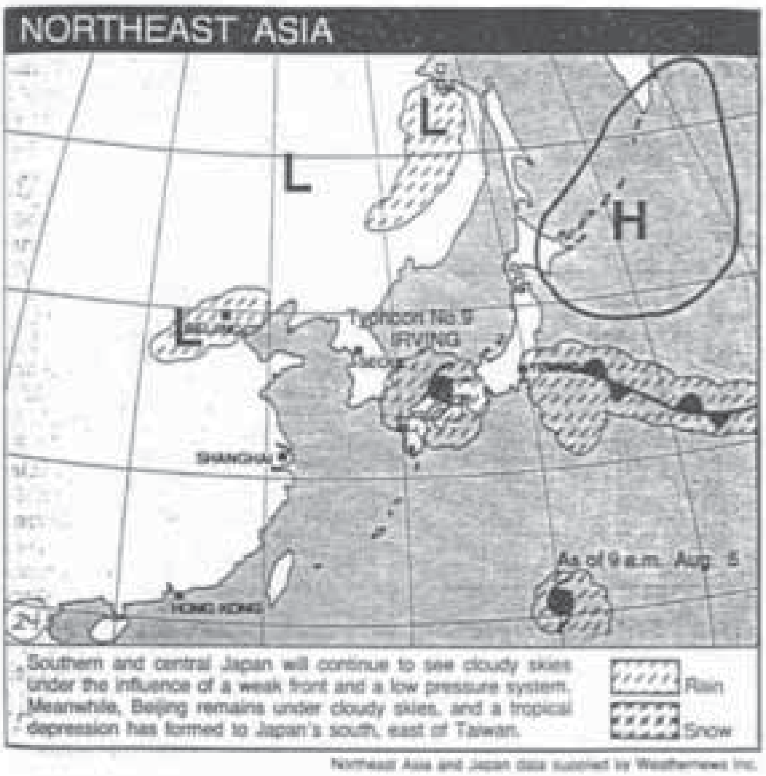

NORTHEAST ASIA
L
L
H
L
Typhoon No.5
IRVING
SHANGHAI
HONG KONG
As of 9 a.m. Aug. 5
Southern and central Japan will continue to see cloudy skies under the influence of a weak front and a low pressure system. Meanwhile, Beijing remains under cloudy skies, and a tropical depression has formed to Japan's south, east of Taiwan.
Rain
Snow
Northeast Asia and Japan data supplied by Weathernews Inc.

fig.12

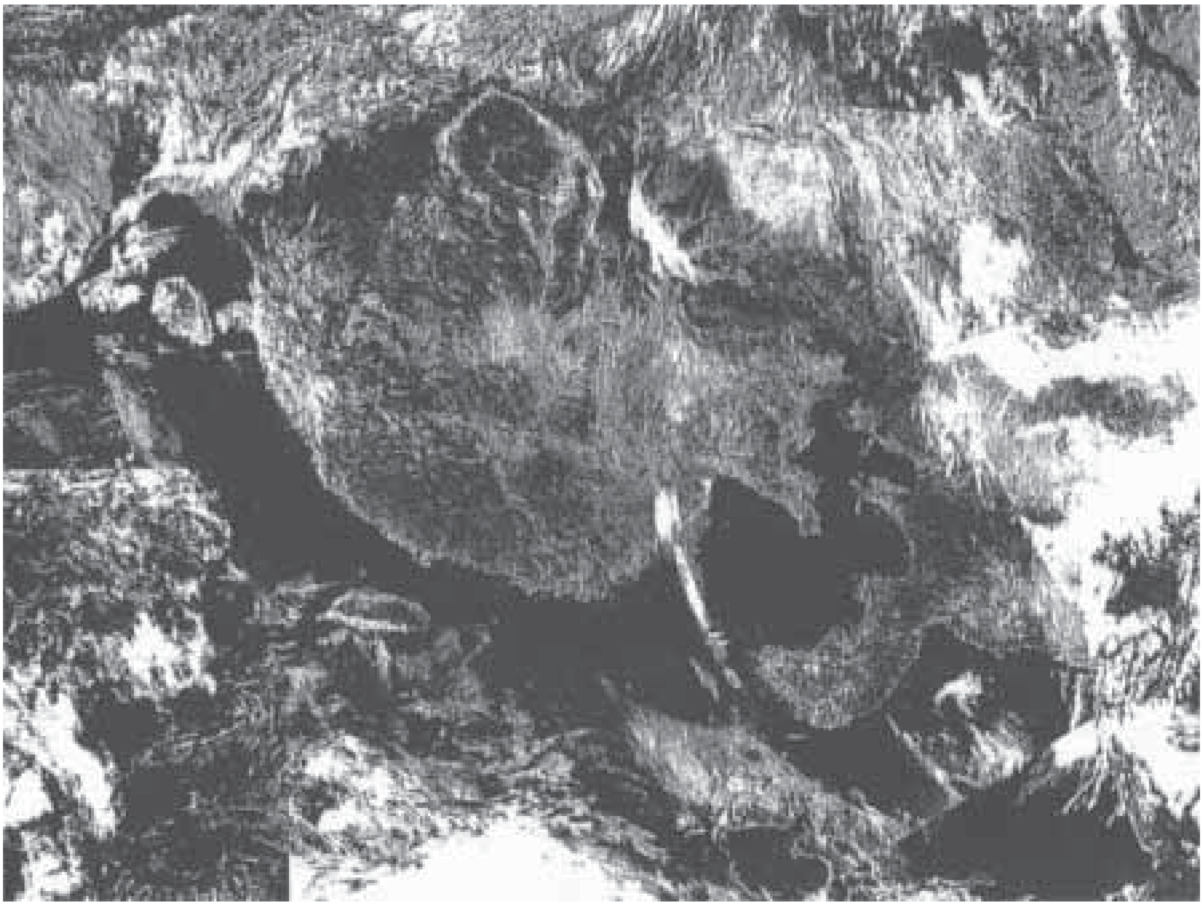
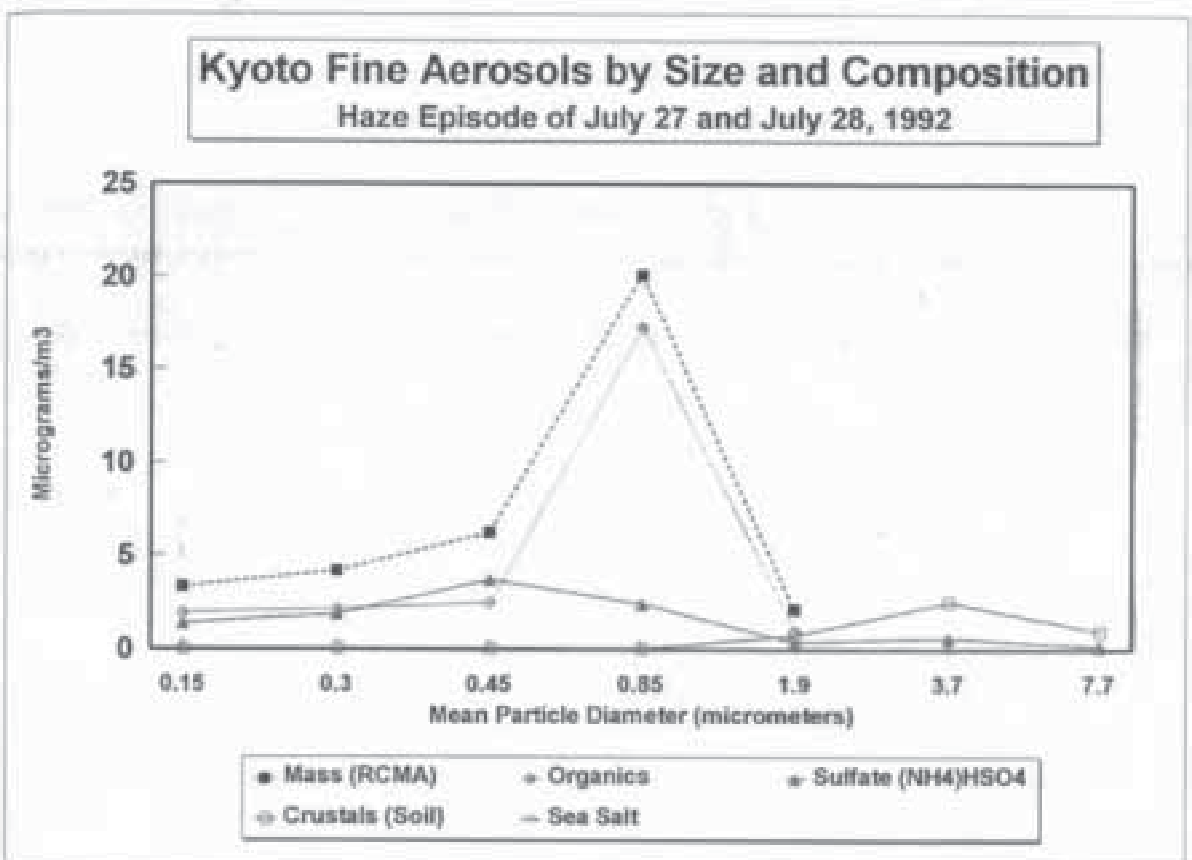
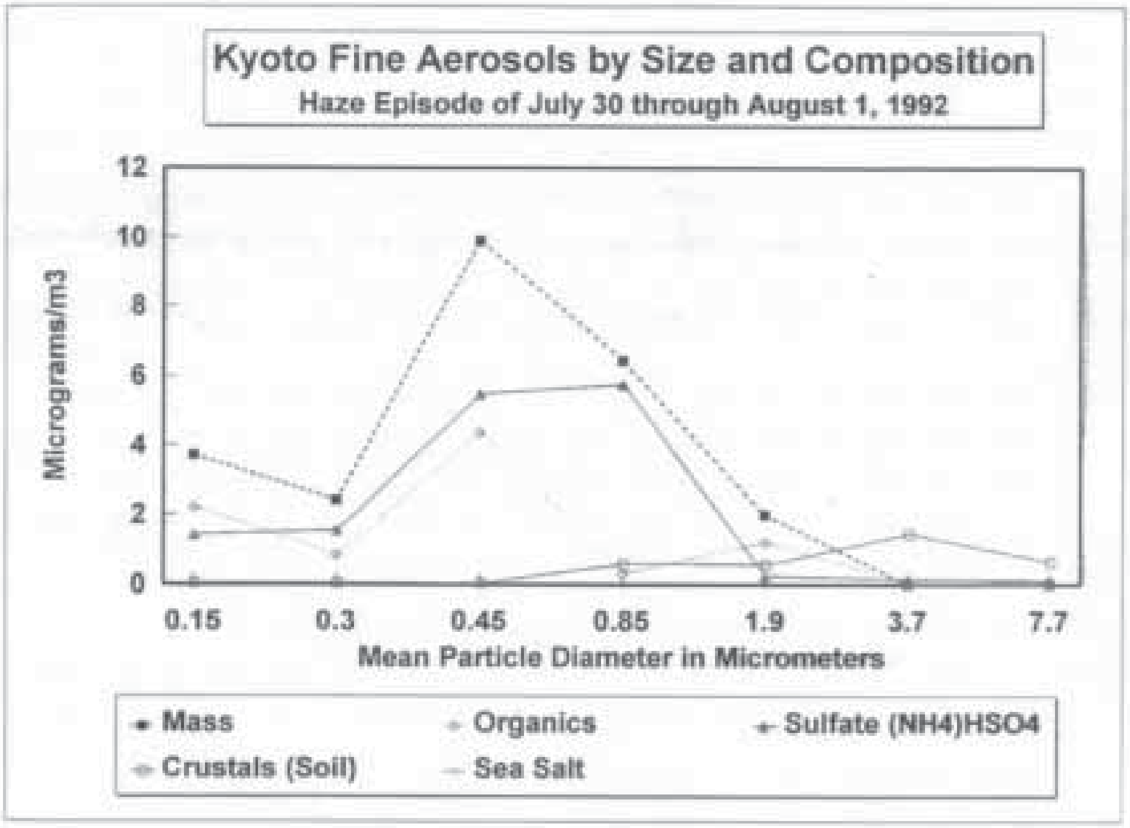


fig.13



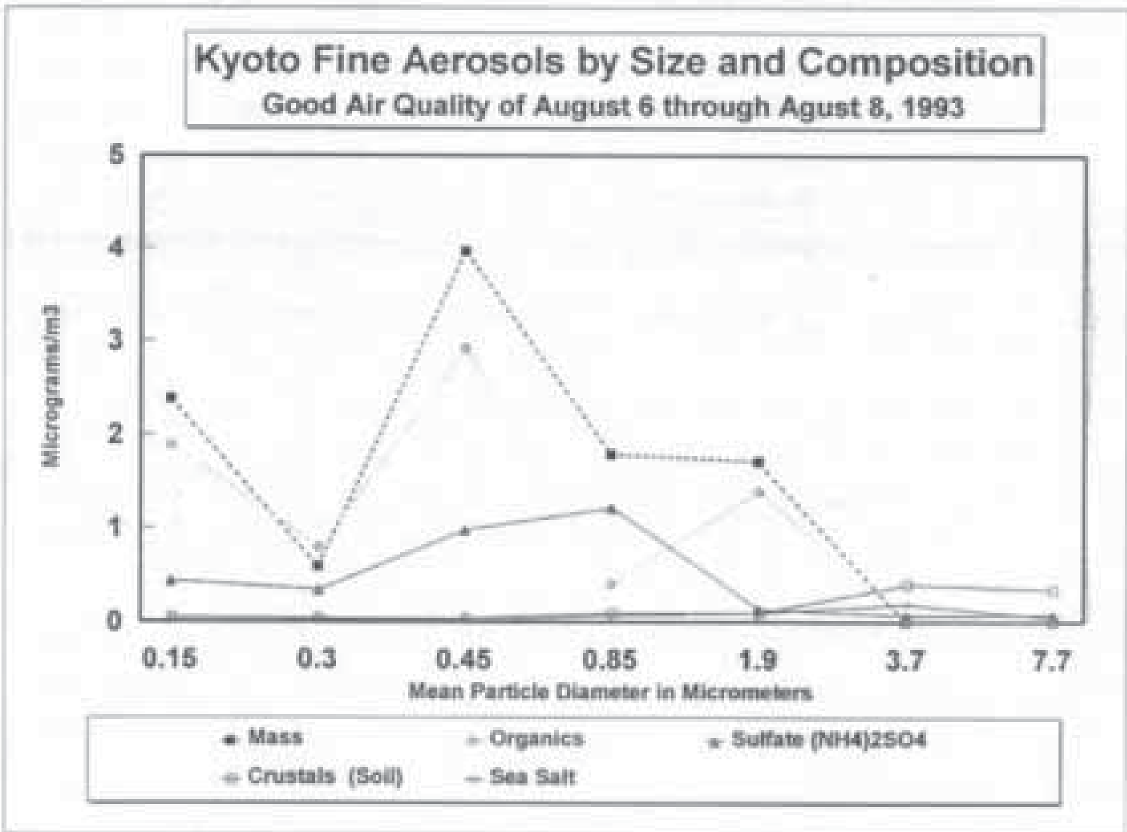
Kyoto Fine Aerosols by Size and Composition
Haze Episode of July 27 and July 28, 1992
Micrograms/m3
25
20
15
10
5
0
0.15
0.3
0.45
0.85
1.9
3.7
7.7
Mean Particle Diameter (micrometers)
Mass (RCMA)
Organics
Sulfate (NH4)HSO4
Crustals (Soil)
Sea Salt

fig.14



Kyoto Fine Aerosols by Size and Composition
Haze Episode of July 30 through August 1, 1992
12
10
8
6
4
2
0
Micrograms/m3
0.15
0.3
0.45
0.85
1.9
3.7
7.7
Mean Particle Diameter in Micrometers
Mass
Organics
Sulfate (NH4)HSO4
Crustals (Soil)
Sea Salt

fig.15



Kyoto Fine Aerosols by Size and Composition
Good Air Quality of August 6 through Agust 8, 1993
5
4
3
2
1
0
Micrograms/m3
0.15
0.3
0.45
0.85
1.9
3.7
7.7
Mean Particle Diameter in Micrometers
Mass
Organics
Sulfate (NH4)2SO4
Crustals (Soil)
Sea Salt

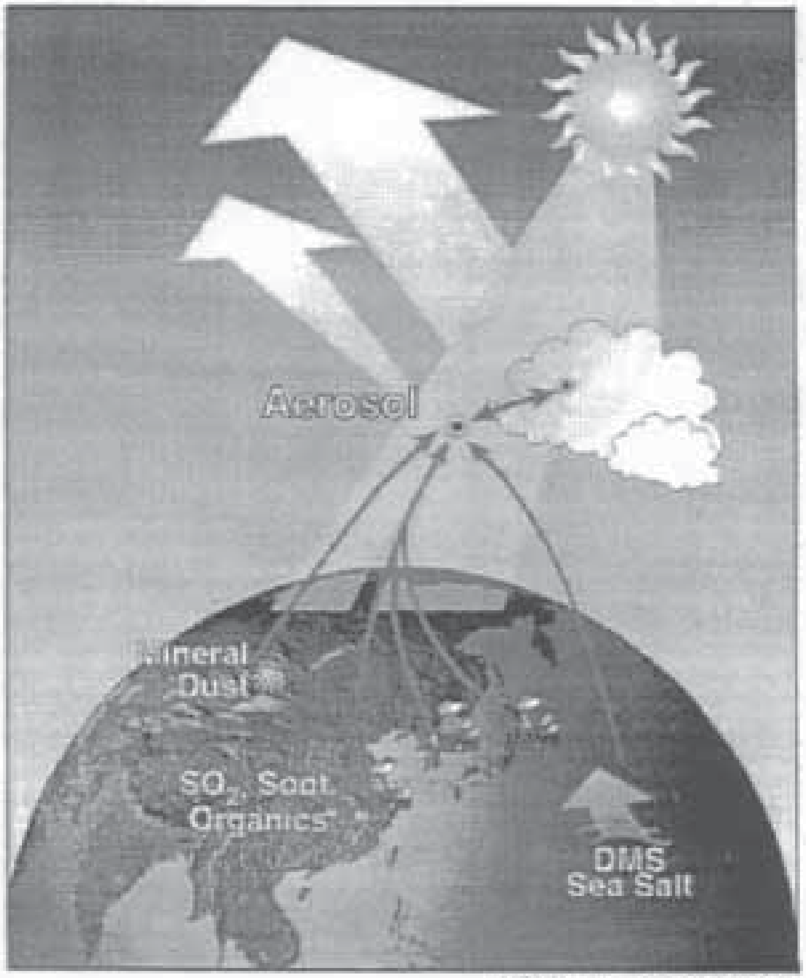
fig.16

International Global Atmospheric Chemistry Project

ACE-ASIA

Asian Pacific Regional Aerosol Characterization Experiment

Radiative Forcing due to Anthropogenic Aerosols over the Asian Pacific Region



Science and Implementation Plan for the ACE-Asia Network Studies

Prepared by:

The ACE-Asia Network Working Group (R. Arimoto and M. Uematsu, co-leaders) and the APARE Coordinating Committee with major contributions from I. Sokolik (optics and radiative fluxes), W. C. Keene (sources and sinks), and P. M. Stegmann (satellite remote sensing).

fig.17

fig.18

Predicted Changes In Global SO2 Emissions (TG/YR)			
Region	1990 Actual	2040 Low estimate	2040 High estimate
PRC China	46.4	86.9	216.0
Russia+ Republics	38.8	42.7	67.3
Western Europe	23.5	18.4	36.7
United States	22.0	22.5	42.6
Eastern Europe	17.1	20.5	33.3
India	12.5	22.8	49.4
Rest of World (incl. SE Asia)	71.6	131.6	220.0

Table 2

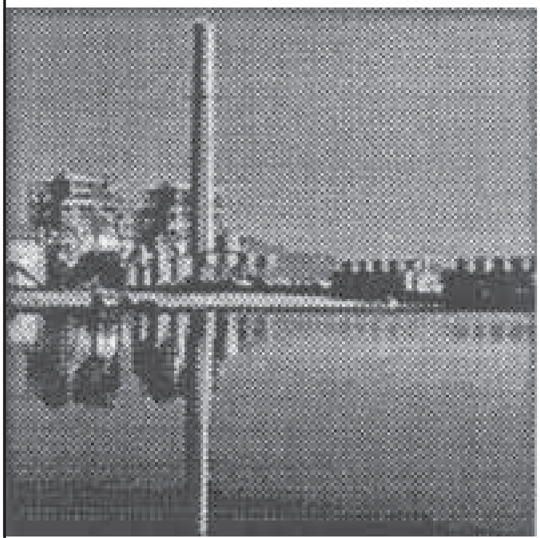
Plant to Clear Canyon Air, Haze-producing Coal Burner to get Cleaner Equipment

By Scott Thomsen The Associated Press

SUMMARY
The owner of a coal-powered plant that contributes to the haze over the Grand Canyon has agreed to install pollution control equipment.

PHOENIX, Oct. 6
The owners of a coal-burning power plant that environmentalists say is a major source of the haze over the Grand Canyon have agreed to install pollution control equipment.
The agreement between the owners of the Mohave Generating Station in Laughlin, Nev. , and two environmental groups was filed today in federal court in Las Vegas. It calls for installation of smoke-stack scrubbers, a filter system, and new burners for the plant's boilers. The project could cost $300 million and is supposed to be finished by 2006. "This is going to be one of the largest cleanups of one of the old coal-powered plants in the West," said Rick Moore, air quality program officer for the Grand Canyon Trust, one of the environmental groups. "This plant regularly belches enormous plumes of soot and smoke." Tuesday, the Salt River Project, a major Arizona utility, announced completion of a $420 million cleanup at a second coal-burning plant accused of polluting the canyon, the Navajo Generating Station near Page. Ariz. "Both of these plants are examples of corporations stepping up to the plate and taking care of their environmental responsibilities," Moore said. "Cleaning....

(10/8/99, From http://www.abcnews.go.com)



The Mohave Generating Station, located along the Colorado River in Laughlin, Nev. Owners of the plant, located about 75 miles from the Grand Canyon, have agreed to install extensive pollution control measures to settle a lawsuit brought by environmentalists. (Southern California Edison)

fig.18