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SUBMITTED TO: Third Interamerican Seminar on Applied Statistics
Applications of Statistics in Business and Actuarial Science
Instituto Tecnologico Automomo de Mexico
Mexico City, Mexico
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ABSTRACT

The Mexican Petroleum Institute (Instituto Mexicano del Petróleo, IMP) and Los Alamos National Laboratory (LANL) are in the first year of a three-year jointly funded project to examine the air quality in Mexico City and to provide techniques to evaluate the impact of proposed mitigation options. The technical tasks include modeling and simulation; monitoring and characterization; and strategic evaluation. Extensive measurements of the atmosphere, climate, and meteorology are being made as part of the study. This presentation provides an overview of the total project plan, reports on the current status of the technical tasks, describes the data collection methods, presents examples of the data analysis and graphics, and suggests roles for statistical analysis in this and similar environmental studies.

1. INTRODUCTION

Environmental issues have international importance and are demanding the attention of world leaders. Our global industrial society has produced and continues to produce a wide variety of pollutants in significant quantities. Thus, any area with a concentration of industrial activities, motor vehicles, and other pollutant generating sources will likely find it beneficial to devote resources to the minimization of waste generation, the clean-up and remediation of existing noncompliance environmental situations, and the implementation and maintenance of policies and practices which meet or exceed local, national, and international standards.

Whether or not the contaminants generated in any particular area accumulate or disperse is highly dependent on topographical and meteorological factors of the immediate and surrounding region. Thus, the amount of resources required to effect change and the extent of change possible depend dramatically upon local and regional atmospheric and topographical conditions which can either support the build-up or contribute to the dispersion of pollutants. To illustrate existing site-to-site differences, Table 1 lists the 1988 concentrations of various pollutants for a selected set of cities. Note that two high-density population areas with many sources of pollutants and with unfavorable topographical conditions are Los Angeles and Mexico City.

Significant resources have been invested by various cities and countries to deploy a variety of environmental monitoring equipment. The various types of equipment collect measurements on atmospheric and environmental variables related to pollutant concentrations and dispersion. Qualitative and quantitative data so collected are summarized and analyzed to provide information to those officials who are responsible for decisions related to issues such as public health, pollution control, environmental clean-up, and visibility. The information is also used for environmental research including the development and validation of computer simulation models. Environmental monitoring activities afford statisticians and other analysts a dual opportunity (1) to access interesting real-world data for study and research and (2) to contribute input to decision-makers responsible for institutional decisions. As members of interdisciplinary research teams, statisticians can provide expertise to pool/combine available data from established monitoring stations, from different sources/instruments, taken at different times, and without specific experimental plans; to formulate both technical and policy questions so quantitative data is useful to the decision-maker; to evaluate and validate models using sensitivity analysis and goodness-of-fit techniques; to design future data collections which complement existing data and optimize resource expenditures; and to develop decision analysis methods.

To illustrate the types of data and the potential for analysis afforded by any of the many existing environmental monitoring and research efforts at various worldwide sites, this paper describes an international cooperative environmental research initiative focused on air quality in Mexico City. An overview of the project, a summary of the technical tasks, and a discussion of potential roles for statisticians in this and similar environmental studies are provided.

2. MEXICO CITY AIR QUALITY RESEARCH INITIATIVE: AN OVERVIEW

The air pollution situation in the Mexico City Basin is representative of critical air quality problems which exist in many major metropolitan areas worldwide. Therefore, any lessons learned in Mexico City can be applied throughout the world. Discussions held during exchange site visits by representatives of the Mexican and United States Governments identified air quality as a potential area of collaboration. Subsequent exchange visits and discussions by technical personnel from the two countries produced a cooperative work plan for a three-year project (Mexico City Air Quality Research Initiative (MARI)) to be jointly funded by Mexico's Petróleos Mexicanos (PEMEX) and the U. S. Department of Energy (DOE). Each funding agency has agreed to provide half of the $9M three-year budget. The Mexican Petroleum Institute (IMP) and the Los Alamos National Laboratory (LANL) were designated as the lead research/technical institutions by the two funding agencies. The two lead research entities are obtaining technical assistance and expertise from other organizations as appropriate.

MARI is a comprehensive study of Mexico City's air quality which includes source identification and characterization; review of existing sampling plans and data; air sampling and monitoring by new technologies; identification of air pollutants; environmental chemical reaction studies; data summarization, analysis, and presentation; and computer modeling. A technical goal is to provide a three-dimensional, real-time picture of the Mexico City atmosphere to include wind flow and turbulence along with the concentration of all of the environmentally important chemical species. MARI will not make or recommend any specific policies, rather the initiative will assist decision makers by providing quantitative information in the form of field observations; of models which use available data and policy information to assess environmental impact and conduct socio-economic evaluations of proposed mitigation options; and of decision analysis techniques for ranking options with respect to multiple criteria.

MARI is a three-year effort with three separate technical components: Task 1-Modeling and Simulation; Task 2-Measurement and Characterization; and Task 3-Strategic Evaluation.

Task 1: Modeling and Simulation. The focus of Task 1 is airshed modeling to be accomplished by using atmospheric chemistry, meteorological, and dispersion models either alone or in appropriate combinations. Prediction of the spatial and temporal variations of selected air quality parameters as a function of mitigation strategy is the purpose of this task.

We have adapted LANL mesoscale meteorological models to simulate the Mexico City Basin in a nested grid simulation with a 6 km^2 outer grid (see Figure 1) encompassing the mountains around the Valley and a 2 km^2 inner grid (inner box in Figure 1) for greater detail in the urban area of the City. The model has been tested by simulating the meteorology of Mexico City on a specific date when the City had poor air quality conditions. In combination with a transport and dispersion model; the winds and the emission and dispersion of carbon monoxide have been simulated for that date with reasonable agreement to the actual measured carbon monoxide levels in Mexico City. The adaptation of these models to the Valley of Mexico will continue as improved information becomes available. One source of new information is the Mexico City data collected in February 1991 by a joint Mexico-United States field exercise team. The chemistry of air pollution in Mexico City is being examined using a variety of models, primarily the Environmental Protection Agency EKMA (empirical kinetics modeling approach) model and the Carnegie-Mellon airshed model, with adaptations to Mexico City as necessary.

An essential component of our modeling efforts is an emissions database which will specify the types and quantities of emissions. These data are crucial to the design and validation of control measures for improving the air quality. We are working with the informal Japan International Cooperation Agency report of 1988 to produce a digitized, spatially resolved annual emissions database for the major inorganic air pollutants. Emissions data for transportation, commercial and industrial sectors being collected by the Mexican Department of the Federal District (DDF)-World Bank will also be added to the project data base.

Task 2: Measurement and Characterization. The focus of Task 2 is the definition of the ambient air quality in the Basin. Field efforts include (1) the use of transportable, self-contained LIDAR (light detecting and ranging) using laser technology for remote sensing and acquisition of three-dimensional real-time aerosol and pollutant concentrations and (2) the deployment of a variety of meteorological equipment.

This task includes two areas of activity: routine monitoring, including long-term measurements; and short-term, intensive field expeditions. Mexican institutions are leading the routine monitoring and long-term measurements efforts which include an air quality ground station network to measure pollutant concentrations and to collect meteorological data; high-volume accumulation of particles to measure airborne metals; and equipment to monitor airborne bacterial contamination. The Mexico Ministry of Urban Development and Ecology (SEDUE) monitoring network provides data for trend and pattern analysis. SEDUE and IMP are also collaborating on source characterization.

IMP and LANL have conducted two joint data collection efforts to complement the foregoing characterization and modeling efforts. A preliminary set of experiments completed in September 1990 was followed by a more extensive set of collaborative observations in February 1991. The data gathered during these efforts are being analyzed and the results, as available, are used to refine the models being developed and used in Task 1. The availability of adequate data which is both current and credible on the existing air pollution situation is essential for accurate simulation of the technical impact of potential mitigation options.

Task 3: Strategic Evaluation. The focus of Task 3 is to provide economic, technical feasibility, social, cultural, political, and institutional analyses for proposed mitigation options to improve the air quality. The modeling system is to use available data to incorporate factors beyond the routine core of technical and financial feasibility and to provide Mexican policy makers valuable diverse background data.

We are developing a framework to evaluate pollution mitigation measures utilizing a decision analysis process. Personnel from IMP, PEMEX, SEDUE, DDF, CONADE (National Commission of Ecology), and LANL participated in a series of meetings to develop general and specific criteria for a decision analysis network as presented in Figure 2. Mexican experts will determine the weighting criteria for parts of the decision tree with respect to their importance in Mexico. The decision analysis network provides a tool for evaluating and ranking pollution control measures with respect to cost, technical, social and political factors as well as the fundamental concern of air quality impact. It is still too early for the data and models to provide precise simulations of impact analyses. However, our goal is to provide accurate and reliable simulations for comparing the impacts of any proposed competing mitigation options and/or strategies. Therefore, two mitigation options are being evaluated to test the viability of the new decision analysis framework. The two options chosen for this initial evaluation are the installation of catalytic converters on new vehicles sold in Mexico City from October 1990 onward and the substitution of natural gas for fuel oil in the two major electric power plants in the Valley of Mexico.

In summary, the Mexico City Air Quality Research Initiative provides a unique opportunity for Mexico and the United States to address an important environmental issue of immediate concern to their citizens and of long-range concern to the global community. The US and Mexican participants in this project are dedicated to using available information, to acquiring new but complementary information, and to developing tools for evaluating options for improving the air quality in Mexico City. The results of this research initiative should be relevant and applicable to urban pollution problems existing around the world.

3. DATA, FIELD MEASUREMENTS, MONITORING, AND EXPERIMENTS

Historical Data. SEDUE has used an environmental monitoring network in the Mexico City Basin to collect a variety of important data since 1986. Locations of current monitoring equipment are shown on the map provided as Figure 3. (Note that the area of the map in Figure 3 corresponds to the inner box on the map presented as Figure 1.) Table 2 lists the sites and indicates the types of measurements recorded. The data provide historical records and are the basis of published indices for CO, SO_2, and O_3.

Joint Mexican-United States Field Experiment, September 1990. A joint team of Mexican and United States researchers conducted a two week field exercise in Mexico City, September 8-22, 1990. The two experimental sites were the Xochimilco Sports Complex in the southern part of the city and the Los Galeana Sports Complex north of the Mexico City International Airport. Over seventy vertical profiles of wind, temperature, humidity and ozone concentrations were obtained using an instrumented tethered balloon at heights up to 1000 m above ground. Surface meteorological and ozone data was collected at each site. Also, IMP worked with SEDUE and the university to provide synoptic weather data, pollution monitoring network data, airport rawinsonde data and surface radiation data for the observation period. Table 3 gives the locations, data sources, and measurements for the experiments. Early analysis indicates a complicated vertical structure in the boundary layer in Mexico City could be associated with subtle temperature profile perturbations. Ozone vertical profiles often showed discontinuities at the temperature discontinuity with little or no ozone from the surface up to a layer and then a rapid rise in ozone concentration in the upper layer. The raw data from the Los Galeana site around midnight on September 19 as presented in Figure 4 illustrate the ozone and structure statements.

Joint US-Mexican Field Experiment, February 1991. The Instituto Mexicano del Petróleo (IMP) and the Los Alamos National Laboratory (LANL) jointly managed an intensive field measurement program in Mexico City February 9-28, 1991. A variety of instrumentation was deployed to make measurements at four selected locations (see Figure 5) across the greater metropolitan area. On Figure 5, the two sites designated by TL collected tethersonde and LIDAR (light detection and ranging) data, the site designated by L recorded LIDAR data only, and the site designated by T recorded tethersonde data only. In addition to the tethersonde and ozonesonde equipment fielded in September, the National Center for Atmospheric Research of Boulder, Colorado collected data using an instrumented airplane, and the LANL elastic scattering LIDAR mobile unit used laser technology for remote sensing acquisition of three-dimensional real-time aerosol and pollutant concentrations. Auto emissions were measured for ~30,000 vehicles (approximately 1% of the estimated 3M vehicles in the Mexico City basin) by the University of Denver. Other activities included a laser ceilometer for atmospheric aerosol profiles, time lapse photography for visibility and near surface visual layer examination, adsorbtion tube sampling for hydrocarbon and aldehyde analyses, SO_2 measurements by the Mexican Electric Research Institute (DIAL), solar radiation and total suspended particulates measurements by the National University of Mexico (UNAM) Institute of Geophysics, measurement of particulate concentrations and PIXE (particle induced X-ray emission) analysis for airborne metals by the Mexican National Institute of Nuclear Research (e.g., see Figure 6), and the data from ongoing air quality activities. Table 4 provides more detail on the particular sampling experiments fielded and instruments used. Figure 7 provides temperature by altitude and the concentrations of O_3 and CO by altitude. Figure 8 shows the LIDAR signal return as a function of altitude. This signal return is related to atmospheric aerosol density, but is uncorrected for atmospheric extinction.

4. STATISTICS: OPPORTUNITIES TO CONTRIBUTE

The preceding discussion of and illustrations from the Mexico City Air Quality Research Initiative provide examples of both the types of environmental data collected and the preliminary results from early analyses. This is only one of many active environmental projects underway at numerous worldwide locations. Each of the projects alone or subsets of the full set of environmental investigations provide a wealth of data for analysis and present many technical challenges to scientists in general and to statisticians in particular.

The study and modeling of various aspects of any particular environment (e.g., Mexico City) presents many very complex interdisciplinary problems. The availability of many qualitative and quantitative variables; the physical aspects of the study area; the need to calibrate, validate, and perhaps reparameterize models; the existence of monitoring sites and historical data; the limitation of resources; the interface with policy; and the multiplicity of distributed sources of pollutants all contribute to the complexity of the study and illustrate the need for a broad range of disciplines/expertise on the study team. Interactions among the many variables and interested parties involved in any real-world real-time analysis of environmental data necessarily requires trade-offs and decisions on the best use of limited resources. As members of an interdisciplinary technical research team, statisticians can contribute to the effective analysis of existing data; the optimal allocation of available resources to collect additional data; the validation and evaluation of simulation models; and the communication of results to decision-makers. Specific statistical skills and expertise which are applicable to solving environmental problems include the following:

- ◊ Formulating questions of scientific and political interest
- ◊ Determining what information (quantitative or qualitative data) might be useful in answering the questions
- ◊ Evaluating/analyzing existing data with respect to relevant questions
- ◊ Incorporating existing monitoring stations/networks into sampling plans for new experiments
- ◊ Design of experiments (data collection) to optimize the use of available resources
- ◊ Techniques for pooling/combining data from different sources, of differing quality, and of different types including subjective information
- ◊ Decision analysis techniques for evaluating options/strategies
- ◊ Sensitivity/uncertainty analyses for evaluating and validating model performance
- ◊ Data analysis/summarization reports/presentations
- ◊ Communication of analytical results to decision-makers

The analytical skills of a statistician complement those of scientists in the study of complex systems such as a local environment. Further, decisions regarding environmental issues must be made by officials based on the best available information. We believe that scientific research, modeling, and statistical analysis can contribute significantly to the quality of decisions being made to provide a healthy environment at an affordable cost. We can be assured that decisions will be made with or without contributions from statisticians. Therefore, it is important that we use our technical talents to provide each decision/policy-maker complete analyses of available data, tools for evaluating trade-offs among options, the value of additional data/analysis, and reports which are easily understood by and communicated to other decision-makers. In doing so, the ranking of and selecting from among various options should be less contentious and more defensible.

In this paper we have focussed on one research initiative dealing with air quality in Mexico City. There are other air quality initiatives within Mexico City and likely one or more in your home city. To be a contributor to the many independent and important efforts around the world dedicated to improving our air quality, we suggest that you get acquainted with the environmental scientists in your area to understand their problems, to learn about current activities, to see what types of data are collected, to obtain copies of publicly available analyses/data, and to identify areas where your interests and expertise match their programmatic needs. Any effective and productive technical relationship of long standing will need to be built over time, be based on mutual respect, and yield mutual benefits.

In conclusion, much effort and considerable resources have gone into the substantial data collection, modeling, and analysis efforts in the Mexico City Basin. The data are currently being checked, evaluated, validated and analyzed by the IMP and LANL research team and are not yet publicly available. However, the interested researcher can contact Francisco Guzmán at the Instituto Mexicano del Petróleo (telephone 567-92-46) to discuss collaboration with the project. Requests for data from the environmental monitoring network, from researchers not associated with MARI (Mexico City Air Quality Research Initiative), should be addressed to Ing. Rogelio González, Director del Area de Estudios, Ministry of Urban Development and Ecology (SEDUE), Mexico City. All requests should provide credentials and research plans of the individual requesting access to the data.

5. ACKNOWLEDGMENTS

We gratefully acknowledge our appreciation for the efforts of all the scientists, technicians, and managers who are contributing their expertise to the success of this project and to PEMEX and the U.S. DOE for the financial support and technical encouragement which made the project possible. Further, the cooperation of personnel from SEDUE, PEMEX, DDF, and CONADE in providing data, general information, and expertise in determining weights for the decision analysis task.

City	Carbon Monoxide	Ozone	Nitrogen Dioxide	Sulfur Dioxide	Particulate Matter <10 Micrometers	Total Suspended Particulates
	Maximum Concentration (PPM) 8 hour	Maximum Concentration (PPM) 1 hour	Maximum Concentration (PPM) 1 hour	Maximum Concentration (PPM) 24 hour	Maximum Concentration ($\mu g/m^3$) 24 hour	Maximum Concentration ($\mu g/m^3$) 24 hour
Albuquerque, New Mexico	14.3	.109	.086	Low	92	311
Denver, Colorado	18.7	.136	.205	.069	123	344
Houston, Texas	8.2	.250	.190	.055	89	167
Los Angeles, California	27.5	.350	.540	<.05	289	564
Minneapolis, Minnesota	14.2	.127	.328	.127	Not Available	402
Washington, D.C.	5.7	.178	.133	.056	Not Available	153
Mexico City	29.3	.405	.327	.208	378	1494
EPA Standards	9.0	.120	Not Applicable	.140	150	150

Table 1: 1988 Air Quality Measurements -- Maximum Recorded Values

Sources: Tom Driscoll, US Environmental Protection Agency, Dallas, Texas (August 11, 1989)
Margaret Hoggan, South Coast Air Quality Management District, El Monte, California (August 8, 1989)
Victor Paramo, Mexican Ministry for Ecology and Urban Development (SEDUE) (August 9, 1989)

RED AUTOMATICA DE MONITOREO (SEDUE)

ZONA					ESTACION	COORDENADAS												No. de Par.
NW	NE	SE	SW	C		LONGITUD	LATITUD	MET	SO2	PST	CO	O3	NO2	NOx	PM10	NMC	H2S	
*	-	-	-	-	A CUITLAHUAC	99 09'55"	19 28'15"				*							1
*	-	-	-	-	B TACUBA	99 12'08"	19 27'19"	*	*								?	3
*	-	-	-	-	C AZCAPOTZALCO	99 11'55"	19 29'20"		*			*						2
*	-	-	-	-	D IMP	99 08'50"	19 29'25"				*							1
*	-	-	-	-	E VALLEJO	99 09'40"	19 31'03"		*									1
*	-	-	-	-	F TLALNEPANTLA	99 12'17"	19 31'44"	*	*	*	*	*	*	*	*	?		9
*	-	-	-	-	G ATLAN	99 14'32"	19 29'08"	*	*	*		*						4
-	*	-	-	-	H LA PRESA	99 07'04"	19 32'02"		*	*								2
-	*	-	-	-	J LA VILLA	99 07'05"	19 28'08"		*	*								2
-	*	-	-	-	K ARAGON	99 04'30"	19 28'18"			*	*							2
-	*	-	-	-	L XALOSTOC	99 04'47"	19 31'34"	*	*	*	*	*	*	*	*			8
-	*	-	-	-	M LOS LAURELES	99 02'20"	19 34'50"		*	*								2
-	*	-	-	-	N SAN AGUSTIN	99 01'50"	19 31'58"	*	*	*		*						4
-	*	*	-	-	O NEZAHUALCOYOTL	99 01'35"	19 25'09"			*	*							2
-	-	*	-	-	P IZTAPALAPA	99 04'12"	19 21'50"			*	*	*						3
-	-	*	-	-	Q C. ESTRELLA	99 05'50"	19 20'10"	*	*	*	*	*	*	*	*			8
-	-	*	-	-	R TAXQUEÑA	99 07'27"	19 20'11"				*							1
-	-	-	*	-	S SANTA URSULA	99 09'10"	19 18'48"		*									1
-	-	-	*	-	T PEDREGAL	99 12'15"	19 19'30"	*	*	*	*	*	*	*	*			8
-	-	-	*	-	U PLATEROS	99 12'00"	19 22'00"	*		*	*	*						4
-	-	-	-	*	V INSURGENTES	99 09'47"	19 25'22"				*							1
-	-	-	*	-	W BENITO JUAREZ	99 09'35"	19 22'18"				*							1
-	-	-	-	*	X MERCED	99 07'10"	19 25'20"	*	*	*	*	*	*	*	*	?	?	10
-	-	-	-	*	Y HANGARES	99 05'00"	19 25'20"	*	*	*		*				?		5
-	-	-	-	*	Z LAGUNILLA	99 08'05"	19 26'40"				*	*						2
							NUMERO DE ESTACIONES	10	15	15	15	12	5	5	5	3	2	

LEGEND: MET = meteorology; SO2 = sulphur dioxide; PST = total suspended particles; CO = carbon monoxide; O3 = ozone; NO2 = nitrogen dioxide; NOx = nitrogen oxide; PM10 = particles of 10 microns or less in diameter; NMC = non methane hydrocarbons; and H2S = hydrogen sulfide.

Table 2: SEDUE Monitoring Sites with Parameters Measured

EXPERIMENTAL SITES:

1. Xochimilco – Athletic field in sports complex
2. Los Galeana – Mall area of sports complex

DATA SOURCES:

1. Synoptic weather maps
2. Rawinsondes at Mexico City airport (96 soundings
3. SEDUE Meteorological and air quality network
4. Solar radiation data from University
5. Surface Weather Station
6. Instrumented tethered balloon (75 soundings)

SURFACE WEATHER METEOROLOGICAL MEASUREMENTS

1. Wind speed
2. Wind direction
3. Temperature
4. Humidity
5. Total solar radiation
6. Net radiation
7. Wetness sensor
8. Precipitation
9. Logged on Campbell Scientific data logger

SURFACE OZONE MEASUREMENTS

1. DASIBI UV absorption ozone photometer
2. Logged with surface meteorological data

Table 3: Joint Mexico City Experiments by IMP and LANL -- September 8-22, 1990

IMP and LANL scientists and technicians managed the following experiments as part of the Mexico City Air Quality Research Initiative. Instrumentation was deployed at four sites (see Figure 5) within the greater metropolitan zone. The unit responsible for each experiment appears in parentheses following the experiment title.

Automated surface air quality monitoring network: (SEDUE) This experiment is the data routinely collected by the monitoring network presented in Table 2.

SO_2 DIAL: (Mexican Electric Research Institute) This experiment provided remote sensing LIDAR for range resolved measurements of atmosphere SO_2 concentrations.

Rawinsondes: (Mexico National Meteorological Service) Free flying balloons launched at a schedule of 7 per day from the Airport. Measurements of atmosphere meteorological parameters were returned via telemetry.

Solar radiation: (UNAM) The Institute of Geophysics reports solar radiation measurements.

Total suspended particulates (TSP): (UNAM) The Institute of Geophysics records measurements of TSP at selected sites.

TSP and PM-10: (National Institute of Nuclear Research) Concentration measurements of TSP and PM-10 (particulate matter of 10 micrometers diameter or less) along with PIXE analyses of airborne metals are reported.

Tethersonde: (LANL) A Tethered balloon provides vertical profiles of temperature, humidity, wind speed, wind direction and pressure up to 1 km above the surface.

Ozonesonde: (LANL) instruments flown with the tethered balloon provide vertical profiles of ozone concentration.

Laser ceilometer: (LANL) Provides range resolved 1-D atmospheric aerosol profiles.

Time lapse photography: (LANL) Records visibility and near surface visual layers.

Air sampling: (LANL) Adsorbtion tube sampling provides hydrocarbon and aldehyde analyses.

Elastic scatter LIDAR: (LANL) Provides range resolved 2-D and 3-D atmospheric structure, plume dynamics, and source analyses.

Auto emissions: (University of Denver for LANL) Remote real-time measurements of CO, CO_2 and hydrocarbon content of exhausts from approximately 30,000 vehicles.

NCAR King Air Instrumented aircraft: (National Center for Atmospheric Research for IMP) Measurements from aircraft platform included meteorological parameters; concentrations of CO, CO_2, O_3, and NO_x; aerosol concentrations and size distribution; surface temperature and UV radiometer.

Other Mexico City activities related to air quality but independent of above experiments:
Viable particles: (UNAM) Center of Atmospheric Sciences measures airborne bacteria.
Biomonitoring: (IMP) Long term sampling of atmospheric metals through uptake by lichens.
Doppler sound: (SEDUE) Measures atmospheric structure and winds by sound reflection.
Visibility: (National Meteorological Service) Visibility observations taken along with other meteorological measurements.

Table 4: Joint Mexico City Experiments by IMP and LANL -- February 9-28, 1991

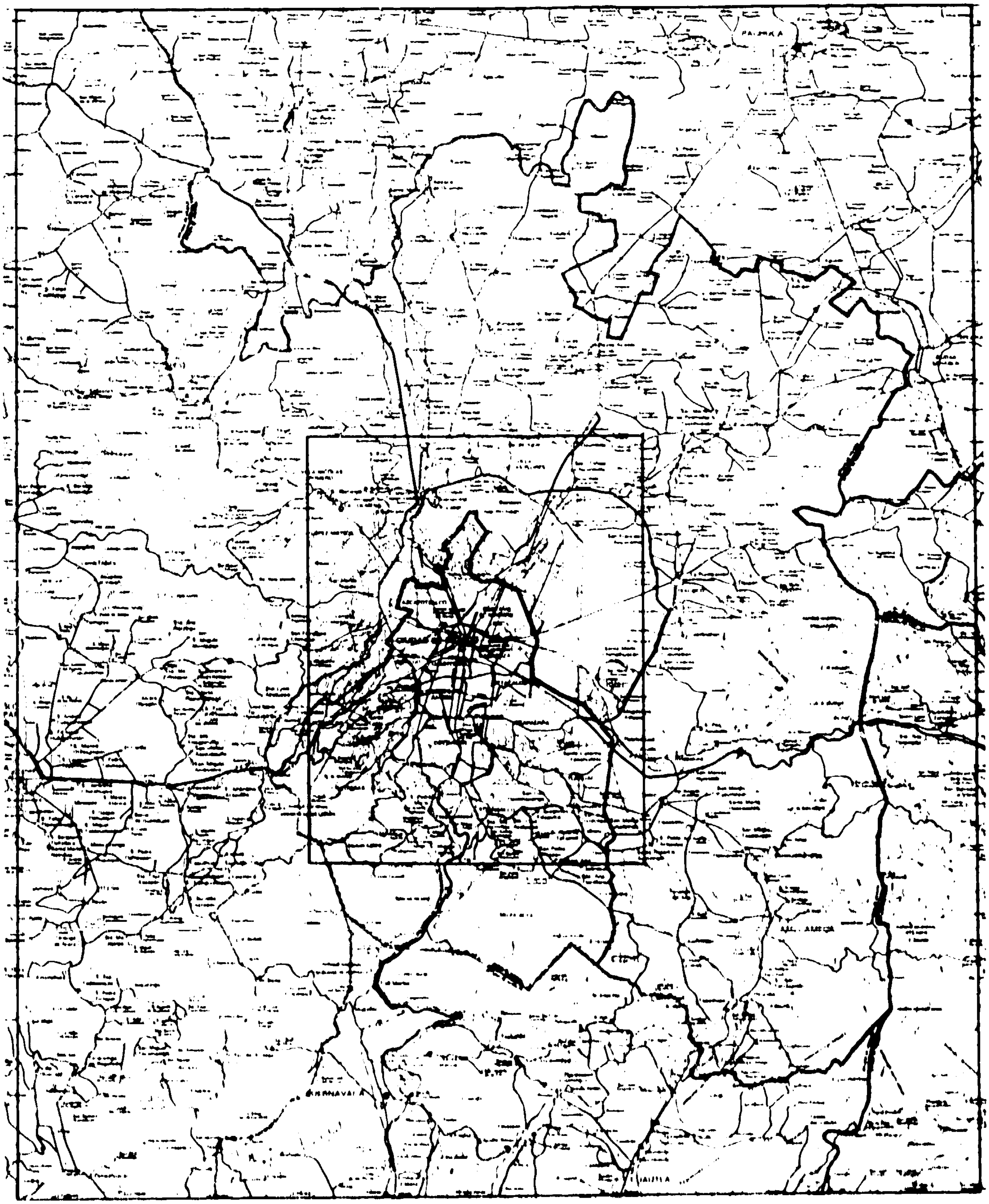

Figure 1: Map outlining 6 km2 and 2 km2 regions used in atmospheric modeling efforts.

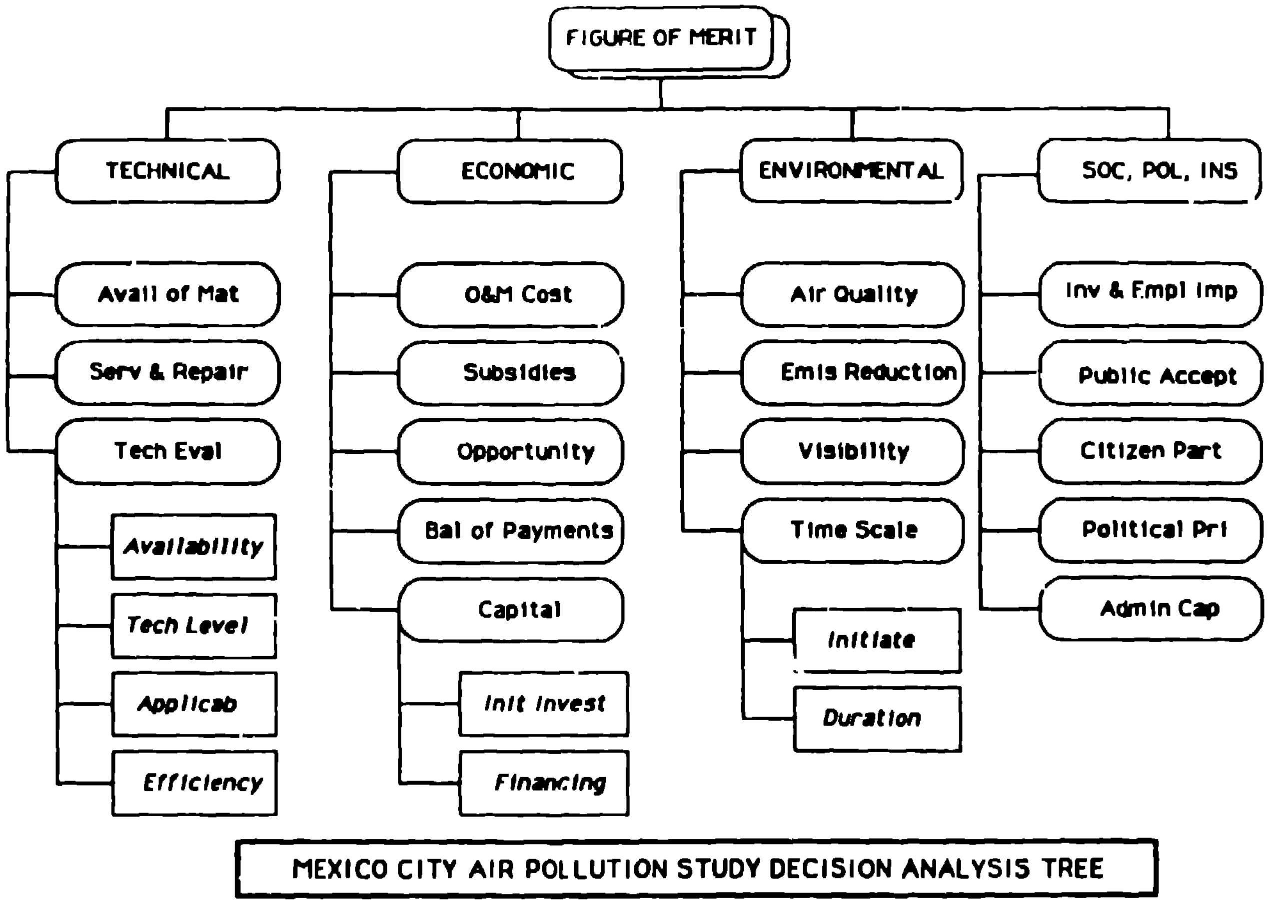

Figure 2: Decision Analysis Tree.

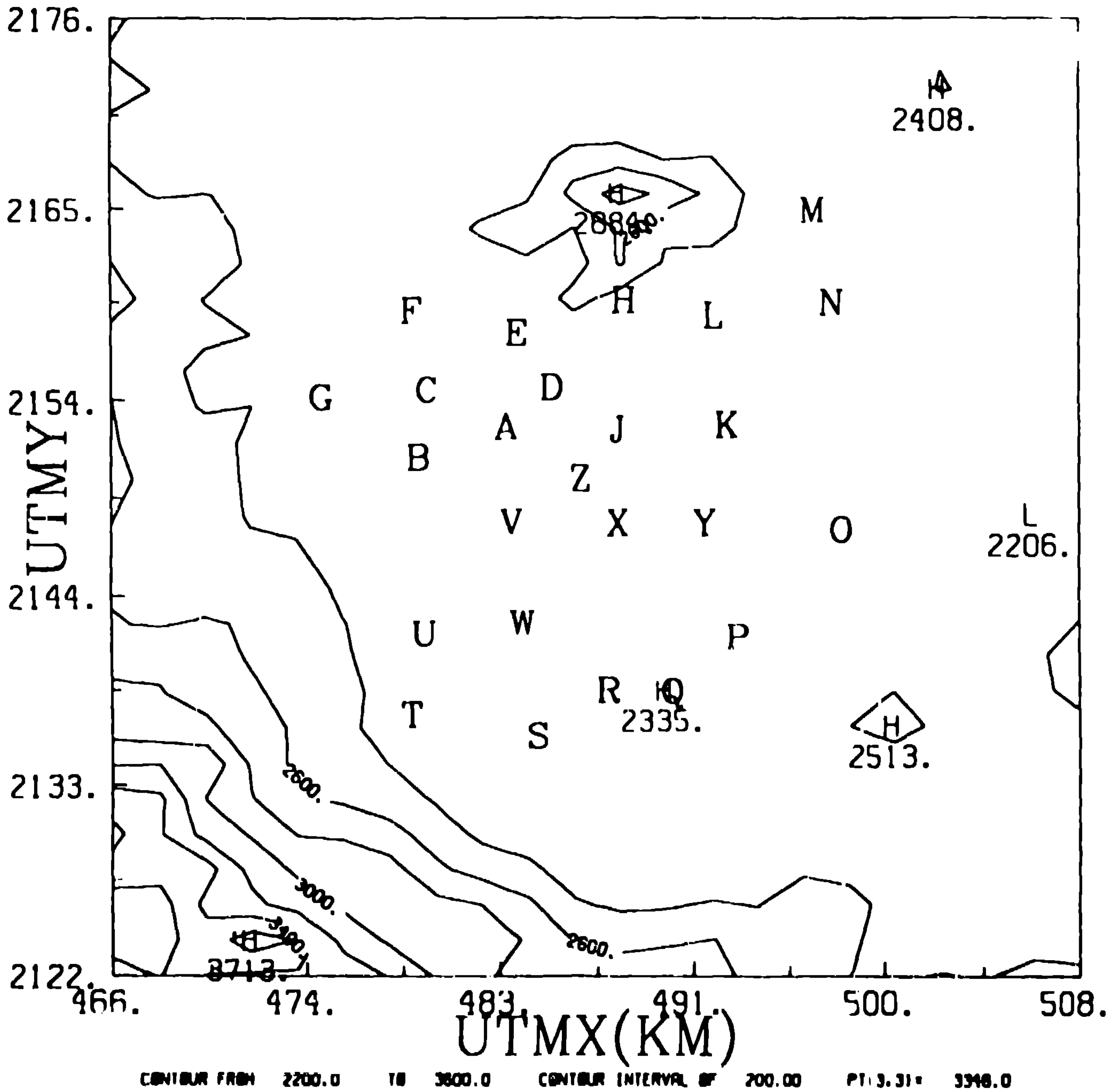

Figure 3: Location of SEDUE monitoring network.

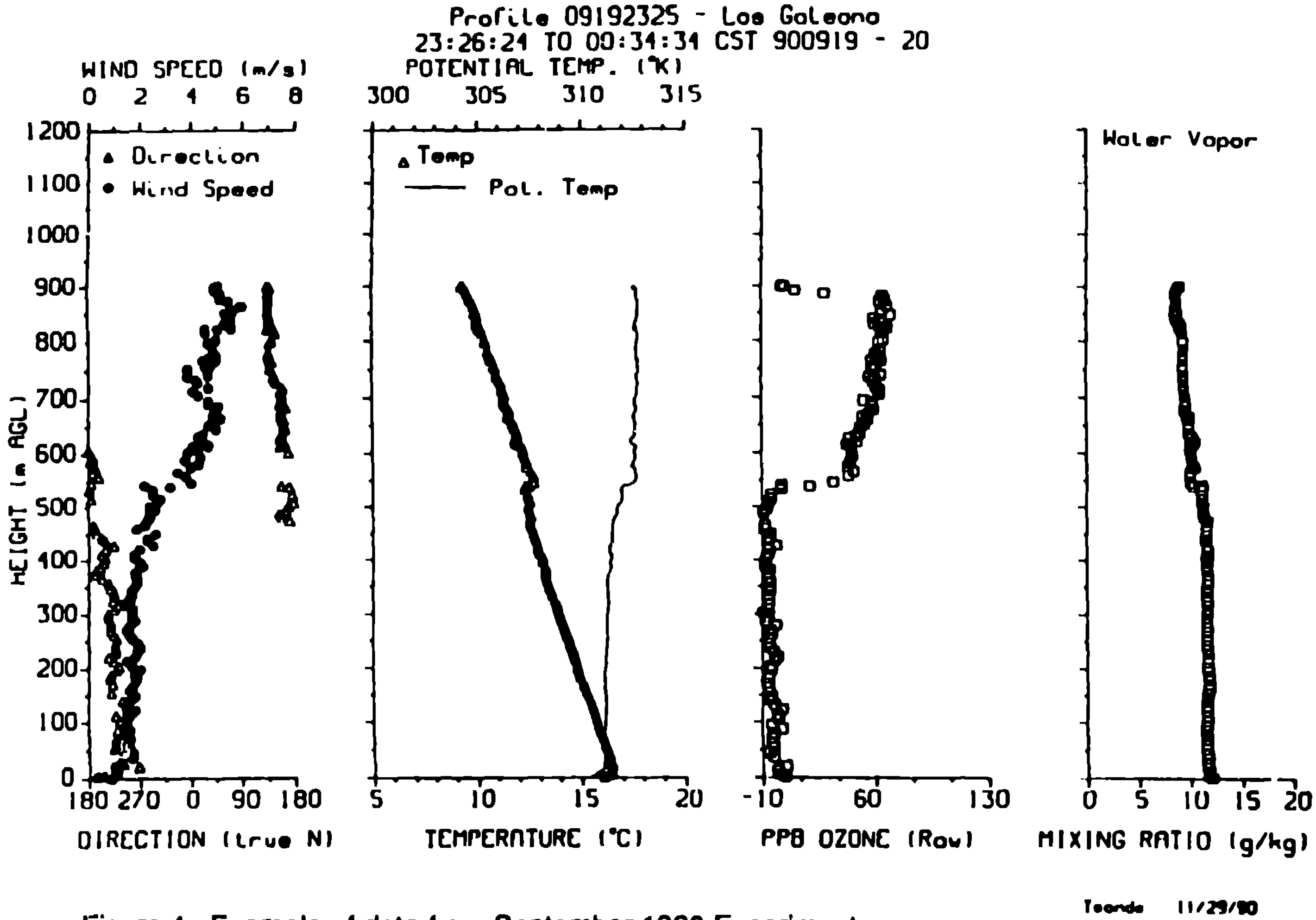

Figure 4: Example of data from September 1990 Experiments.

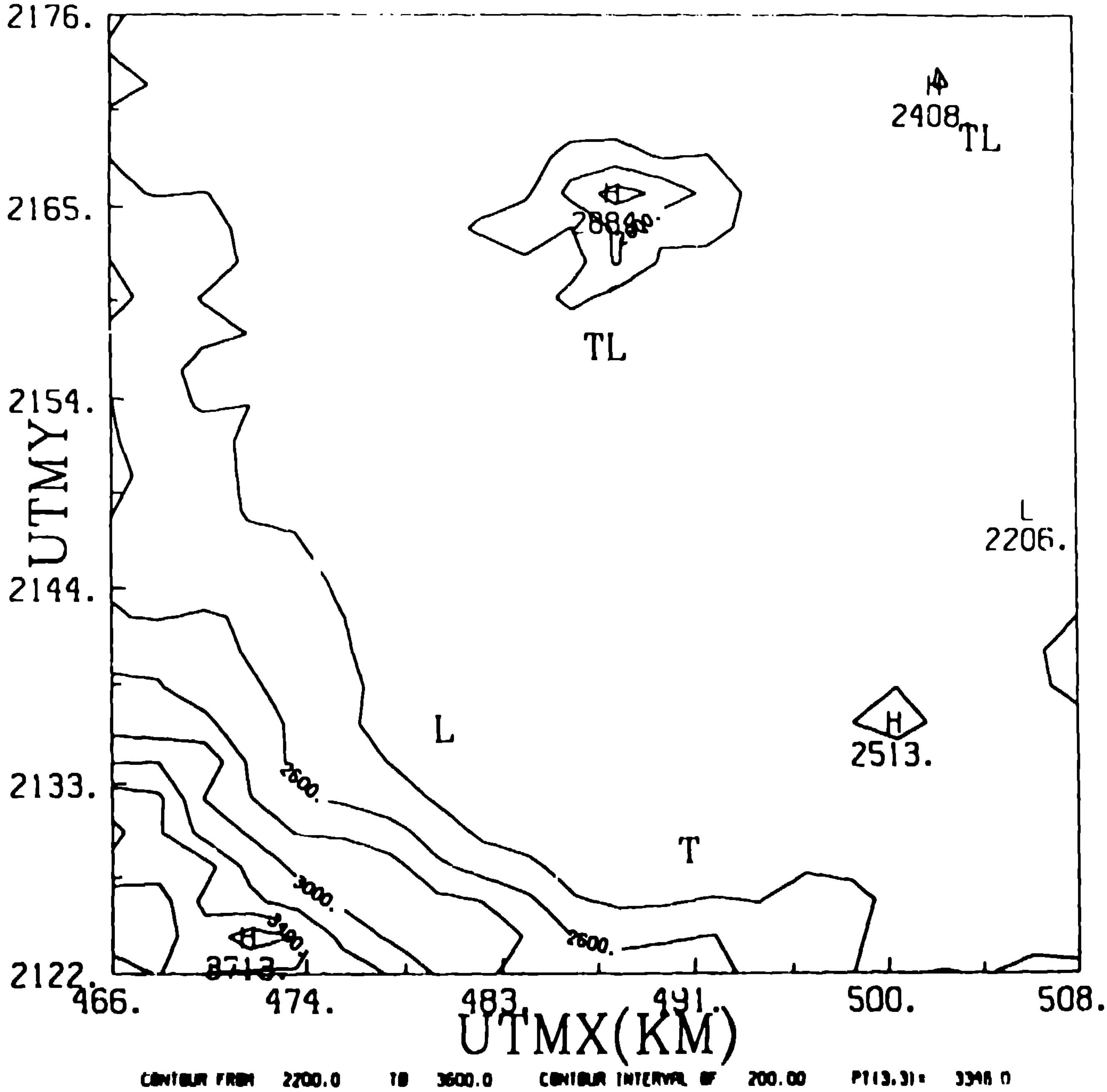

Figure 5: Location of four experimental sites for February 1991 Experiments. "TL" denotes both tethersonde and LIDAR data, "T" denotes tethersonde data only, and "L" denotes LIDAR data only.

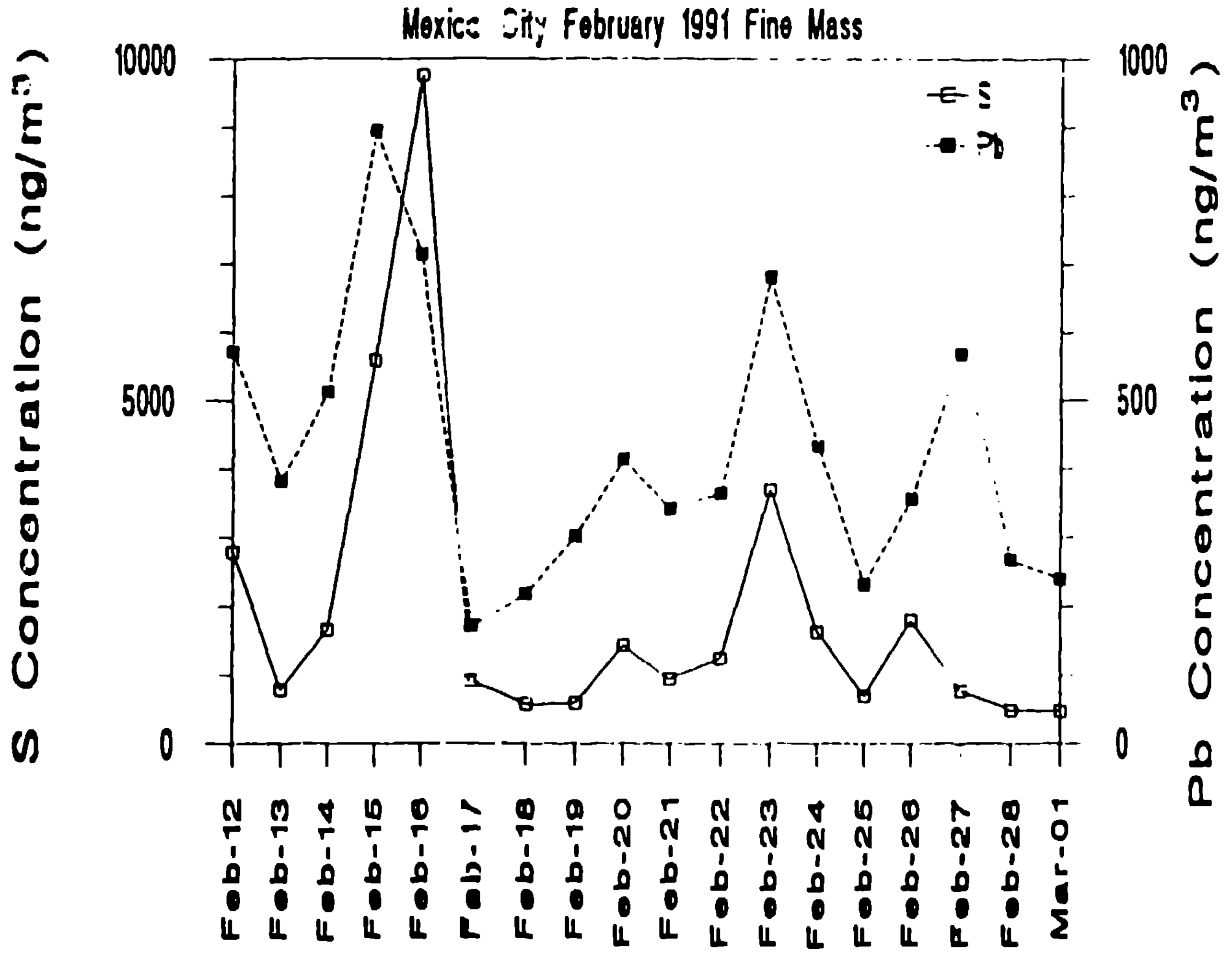

Figure 6: Graph of sulphur and lead concentrations for February 1991 Experiments.

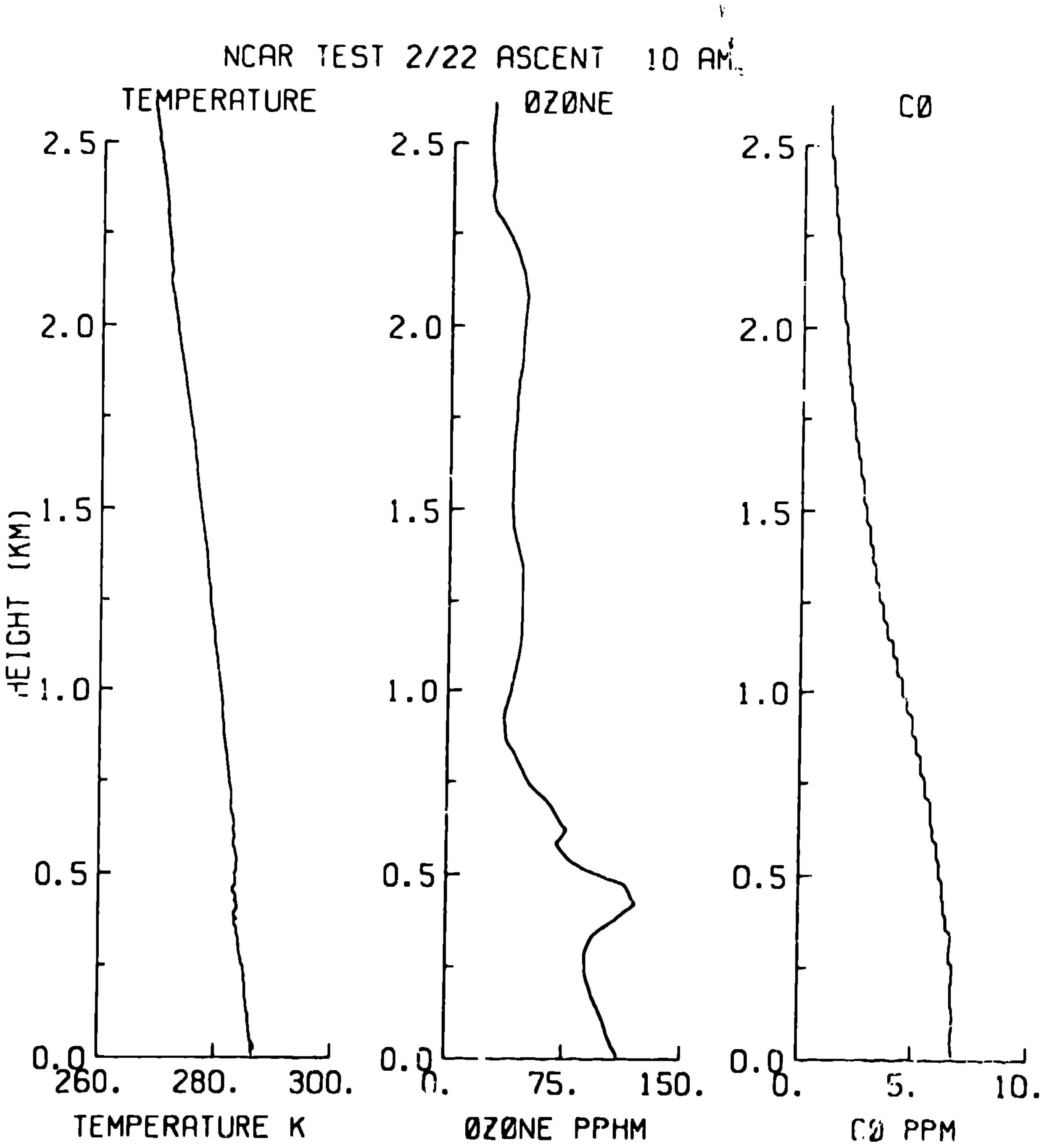

Figure 7: Temperature, ozone, and carbon monoxide data from February 1991 Experiments.

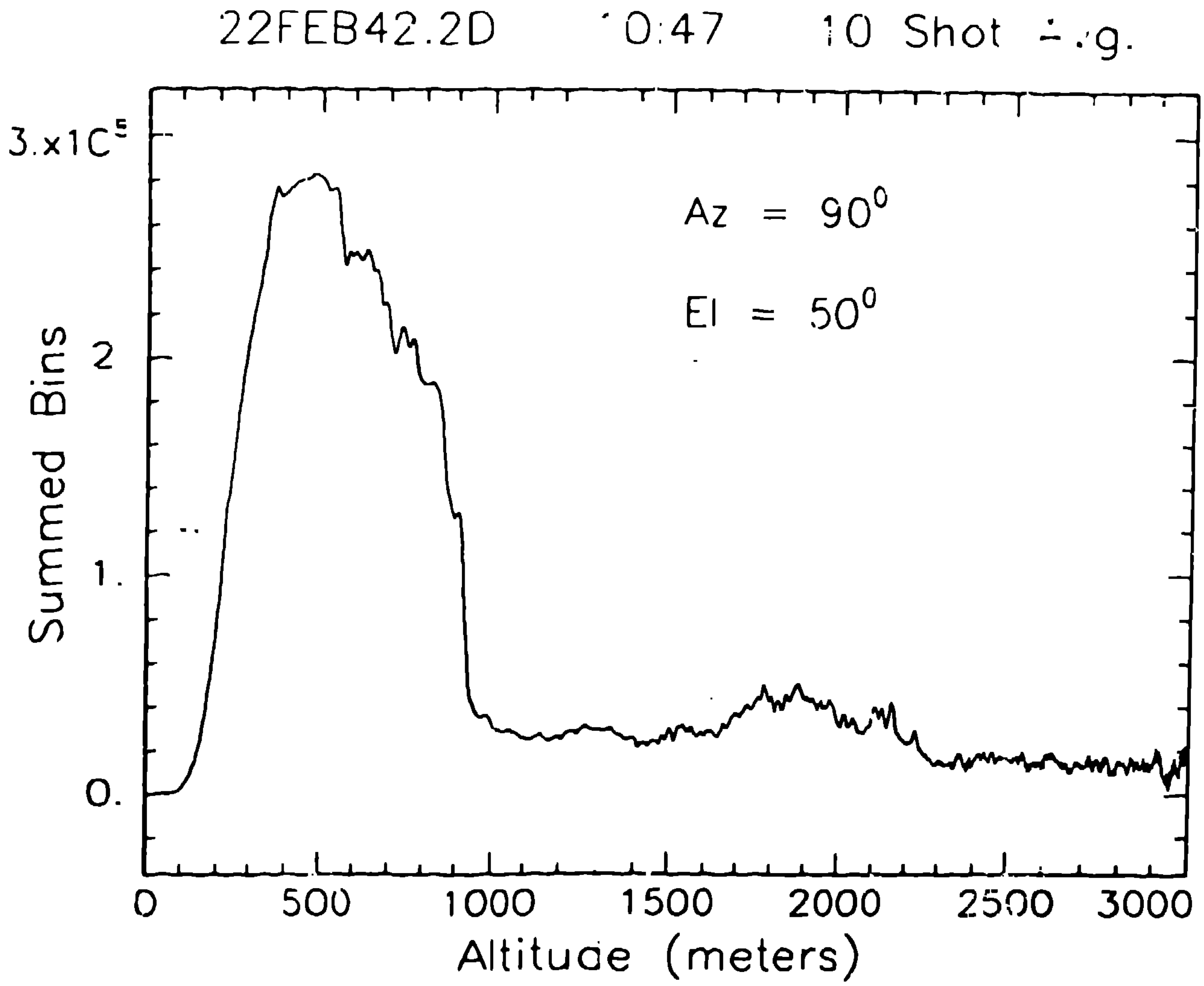

Figure 8: Example of LIDAR data from February 1991 Experiments.