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Winter Season Air Pollution in El Paso-Ciudad Juarez

A Review of Air Pollution Studies in an International Airshed

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A Review of Air Pollution Studies in an International Airshed

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submitted to

Environmental Protection Agency - Region VI
Air, Pesticides and Toxics Division

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Abstract

This report summarizes a number of research efforts completed over the past 20 years in the El Paso del Norte region to characterize pollution sources and air quality trends. The El Paso del Norte region encompasses the cities of El Paso, Texas and Ciudad Juarez, Chihuahua and is representative of many US-Mexico border communities that are facing important air quality issues as population growth and industrialization of Mexican border communities continue. Special attention is given to a group of studies carried out under special US Congressional funding and administered by the US Environmental Protection Agency. Many of these studies were fielded within the last several years to develop a better understanding of air pollution sources and trends in this typical border community. Summary findings from a wide range of studies dealing with such issues as the temporal and spatial distribution of pollutants and pollution potential from both stationary and mobile sources in both cities are presented. Particular emphasis is given to a recent study in El Paso-Ciudad Juarez that focussed on winter season PM_{10} pollution in El Paso-Ciudad Juarez. Preliminary estimates from this short-term study reveal that biomass combustion products and crustal material are significant components of winter season PM_{10} in this international border community.

Acknowledgements

This report summarizes the efforts of many federal, state and local agencies, private-sector contractors, universities and national laboratories who have collectively produced a sizeable body of information dealing with air quality issues in the El Paso del Norte region. In preparing this review, the authors have attempted to give appropriate credit to participants through the use of numerous citations in the text.

While personnel from the Texas Natural Resource and Conservation Commission (formerly the Texas Air Control Board) and Sandia National Laboratories took the lead role in the design and data analysis associated with the short-term winter season PM_{10} study, the diligent efforts of many individuals from the organizations listed below enabled a satisfactory completion of the study.

El Paso City-County Health Department
US Environmental Protection Agency - Region 6
US Environmental Protection Agency - Atmospheric Research and Exposure Assessment Laboratory
Secretariat of Social Development of Mexico
City of Juarez Health Department
Science Applications International Corporation
Radian Corporation
Lawrence Berkeley Laboratory
Sunset Laboratory

A number of Sandia and contract personnel made important contributions to the project. Gary Brown, Mark Ivey and Monty Apple played important roles in meteorological instrumentation setup and maintenance along with field data collection during the short-term study. Chris Erickson and Laura McCarty were instrumental in making the necessary modifications to the Diagnostic Wind Field Model from the Urban Airshed Model such that it would run on a Sandia computer. They also designed and implemented the post-processor for graphical display of the computed results.

This work was sponsored by the US Environmental Protection Agency-Region 6. Mr Jim Yarbrough of the EPA-Region 6 Air Programs Branch was the project officer. A special recognition goes Mr. Yarbrough who provided the authors with much of the background information describing early air pollution studies in the region.

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List of Abbreviations and Acronyms

AIRS. . . . . . Aerometric Information Retrieval System
ASARCO. . . American Smelting and Refining Company
ASL . . . . . . US Army Atmospheric Sciences Laboratory
CAA . . . . . . Clean Air Act
CAMS. . . . . Continuous Air Monitoring Station
CMB . . . . . Chemical Mass Balance
CO. . . . . . . Carbon Monoxide
CPM . . . . . . Coarse(>2.5 and <10 micrometer aerodynamic diameter) Particulate Matter
DWM . . . . . Diagnostic Wind Field Model (from the Urban Airshed Model)
EPA-EMSL . Environmental Protection Agency - Environmental Monitoring Systems Laboratory
EPCCHD . . El Paso City County Health Department
FAA. . . . . . Federal Aviation Administration
FEMAP . . . . Federation of Private Health and Community Development Associations
FPM . . . . . . Fine (<2.5 micrometer aerodynamic diameter) Particulate Matter
GC-MS . . . . Gas Chromatography-Mass Spectrometry
HC. . . . . . . Hydrocarbons
Hivol . . . . . High volume air sampler
IAQMD . . . . International Air Quality Management District
I/M . . . . . . Inspection and Maintenance
MST . . . . . Mountain standard time
NAAQS . . . National Ambient Air Quality Standards
NMEID . . . . New Mexico Environment Improvement Division
NWS . . . . . National Weather Service
PAH. . . . . . Polycyclic Aromatic Hydrocarbons
PC . . . . . . Personal Computer
PM_{10}. . . . . . Particulate matter less than 10 micrometers aerodynamic diameter
PM_{15}. . . . . . Particulate matter less than 15 micrometers aerodynamic diameter
PUF . . . . . . Polyurethane foam
RVP . . . . . . Reid Vapor Pressure
SAI . . . . . . Science Applications Incorporated
SCERP . . . Southwest Center for Environmental Research Policy
SEDESOL . Federal Secretariat of Social Development
SEDUE . . . Secretariat of Urban Development
TACB . . . . Texas Air Control Board
THC . . . . . . Total hydrocarbons
TNRCC . . . . Texas Natural Resource and Conservation Commission
TSP . . . . . . Total Suspended Particulate Matter
UTEP . . . . University of Texas at El Paso
UTM . . . . . Universal Transverse Mercator
VMT . . . . . . Vehicle Miles Traveled
VOC . . . . . . Volatile organic compounds
XRF . . . . . . X-ray Fluorescence

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Executive Summary

The western portion of the state of Texas meets the northern part of the Mexican state of Chihuahua and the southern boundary of the state of New Mexico at a strategic mountain pass, referred to by Spanish explorers as "El Paso del Norte" through which the Rio Grande courses its way on its long journey from the high mountains in the state of Colorado to the Gulf of Mexico many miles distant. This important trade route and center of commerce has been inhabited for over 400 years and currently accommodates a population of nearly 1.4 million people on both sides of the international border. The twin cities of Ciudad Juarez (City of Juarez, hereafter Cd. Juarez), Chihuahua and El Paso, Texas share a common international airshed that is partially surrounded by mountains to the north and west of the population center. Both cities are experiencing growth however Cd. Juarez, in particular, is experiencing striking growth as the country of Mexico and the state of Chihuahua makes a transition from an agrarian economy to an industrial economy centered in large urban zones such as Cd. Juarez.

While the country of Mexico and the state of Chihuahua are in principal committed to the preservation and maintenance of clean air resources, at a practical level the degree of pollutant source control on the Mexican side of the border lags considerably behind air pollution characterization and control programs in place on the US side. The existence of sister cities on either side of the border poses special problems for those cities faced with compliance with the US and Mexican clean-air statutes. Local, state and federal agencies have struggled for many years for a mutually satisfactory approach to the problem. The Cd. Juarez-El Paso airshed has historically exceeded US Clean Air Act National Ambient Air Quality Standards for such pollutants as PM_{10} (particles less than 10 μm diameter), CO (carbon monoxide) and ozone. In an effort to address this problem, air pollution officials in the State of Texas and the City of El Paso have lobbied the US EPA for many years to provide a Federal mechanism by which air pollution characterization and control strategy development could be achieved by international cooperation in the area. In recent years, the Mexican Federal Secretariat of Social Development (SEDESOL) and its predecessor the Secretariat of Urban Development and Ecology (SEDUE) the agency that is analogous to the US EPA, has taken a more active interest in U.S-Mexico border air pollution problems. Factors such as these figured prominently in the successful negotiation and approval of the so-called Annex V that is part of the 1983 US-Mexico Border Environmental Agreement dealing in particular with air pollution issues along the US-Mexico border. Finalization of this agreement in 1989, and the appropriation of funds by the US Congress, also in 1989, laid the groundwork for a series of joint US-Mexico air pollution studies designed to more fully understand pollution sources and their impacts on both sides of the border.

A number of research efforts to characterize pollution sources and air quality trends completed over the past 20 years in the El Paso del Norte region are summarized in this report. Early studies concentrated on definition of stationary sources such as local copper smelters and petroleum refineries. Later studies have focussed upon PM_{10} pollution in particular since the region shows non-attainment for current US PM_{10} standards when both US and Mexican sources are taken into account. Summary findings from the collection of studies reviewed in this report are more fully summarized below.

> **Industrial stationary sources do not contribute significantly to airborne particulate matter in the El Paso del Norte region** - Studies in the 1980's focusing on total suspended particulate matter and more recent studies dealing with PM_{10} both reveal that large industrial stationary sources such as copper smelters in the region are minor contributors to winter season airborne particulate matter.

Winter season PM_{10} levels are highest in the Cd. Juarez-El Paso downtown areas and in general show a concentration gradient increasing toward Mexico - A number of studies, among them the EPA-EMSL airborne lidar study, EPA-6 saturation PM_{10} study, and the short term winter PM_{10} study, all reveal higher PM_{10} levels as one moves toward Cd. Juarez. Further indirect evidence for this concentration gradient comes by way of the TNRCC PM_{10} SIP analysis which reveals that no exceedences of PM_{10} are predicted in El Paso if only El Paso particulate matter sources are taken into account. In actual studies, however, PM_{10} concentration levels in excess of air quality standards are encountered on both sides of the border.

Emissions from the average vehicle in Cd. Juarez are about three-fold higher than from the average vehicle in El Paso - The University of Denver remote sensing studies for tailpipe CO and hydrocarbons show that while the amount of pollutants emitted from a high-polluting car is the same in both Cd. Juarez and El Paso, there are more of these high-polluting cars operating in Cd. Juarez than in El Paso. Other studies undertaken to characterize the age of the vehicular fleet in Cd. Juarez reveal that the average age of the fleet is older in Cd. Juarez than in El Paso. This observation is consistent with the measured higher tailpipe emissions in Cd. Juarez.

Vehicle miles traveled in El Paso are about three-fold higher than in Cd. Juarez - Results from a series of studies by the Texas Transportation Institute on vehicle usage in Cd. Juarez reveal about 3.4 million anuual VMT in Cd. Juarez as compared to 9.9 million annual VMT in El Paso. Per capita mileage in El Paso is about six-fold higher than in Cd. Juarez revealing very different vehicle usage patterns in the two cities. Should Cd. Juarez residents adopt US driving habits, vehicular emissions could significantly increase in the Paso del Norte region.

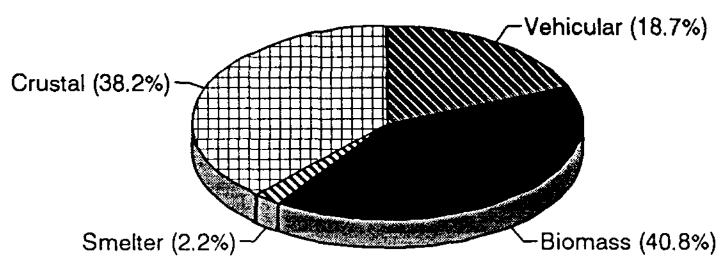
Winter stagnation events and complex terrain significantly limit pollutant dilution within the region -Meteorological data taken during the PM_{10} short term study confirm the presence of very shallow vertical mixing heights in the evening and early morning hours of the winter season. Wind flow at various meteorological monitoring locations throughout the El Paso del Norte region reveal local terrain influence during winter stagnation periods. Wind fields predicted by the Diagnostic Wind Field Model show general agreement with observed winds. A rigorous comparison was not carried out between measured and predicted wind flow as a part of this study however. In some test cases abnormal discontinuities in the predicted wind fields were observed suggesting that optimization of the model may be required to obtain representative results.

Winter season PM_{10} in the Paso del Norte region reaches levels in excess of the National Ambient Air Quality Standard - Analyses completed by the TNRCC as a part of the short term winter PM_{10} study revealed numerous exceedences of the 24-hour PM_{10} standard at both Cd. Juarez and El Paso sites during the 1990-91 winter season study period. In some cases, average PM_{10} levels three-fold higher than the US PM_{10} air quality standard were observed.

Aerosol carbon is a major constituent of fine, coarse and PM_{10} aerosol in the region - Carbon species measurements of collected particulate matter reveal aerosol carbon composition much like that observed in other urban areas. High levels of both elemental and volatile carbon are observed and originate from vehicular, biomass combustion and other local combustion sources. Limited measurements of individual toxic aerosol species such as benzo(a)pyrene show that, in general, these vary proportionately with overall aerosol carbon levels. The relatively high levels of elemental or soot carbon have important implications for visibility in the region as well since elemental carbon is an important contributor to visibility reduction.

Crustal and biomass combustion sources together constitute nearly 80 percent of the winter season total PM_{10} measured in the Paso del Norte region - Preliminary estimates of source category strength using tracer elements reveal that crustal and biomass combustion sources are the major contributors to winter season PM_{10}. Average contribution of the crustal source to PM_{10} is about 40%. The crustal source is understood to be closely linked to vehicular sources which are estimated to contribute no more than 20% to total PM_{10}. Vehicle traffic on many unpaved roadways, prevalent in Cd. Juarez residential areas, results in the suspension of both fine and coarse fraction crustal material, thus linking the vehicular and crustal source categories. The use of soil-corrected potassium as a tracer for biomass combustion reveals about 40% average contribution of this source to PM_{10} as well. The use of biomass fuel for the brckmaking industry and for residential heating in Cd. Juarez is suspected to contribute significantly to the overall biomass particulate source category.

The pie chart below illustrates the average degree of source contribution to winter-season PM_{10} pollution from all El Paso-Cd. Juarez sites and sampling periods as measured during the Winter 1990 PM_{10} Scoping Study.



El Paso-Cd. Juarez Winter Air Quality
Source Category Contribution to PM-10

1.0 Introduction

The western portion of the state of Texas meets the northern part of the Mexican state of Chihuahua and the southern boundary of the state of New Mexico at a strategic mountain pass, referred to by Spanish explorers as "El Paso del Norte" through which the Rio Grande courses its way on its long journey from the high mountains in the state of Colorado to the Gulf of Mexico many miles distant. This important trade route and center of commerce has been inhabited for over 400 years and currently accommodates a population of nearly 1.4 million people on both sides of the international border. The twin cities of Ciudad Juarez (City of Juarez, hereafter Cd. Juarez), Chihuahua and El Paso, Texas share a common international airshed that is partially surrounded by mountains to the north and west of the population center. Both cities are experiencing growth however Cd. Juarez, in particular, is experiencing striking growth as the country of Mexico and the state of Chihuahua makes a transition from an agrarian economy to an industrial economy centered in large urban zones such as Cd. Juarez.

While the US-Mexico border denotes a physical separation between the two countries, it also demarcates significant disparities in the standards of living of inhabitants in El Paso and Cd. Juarez. Evidence of these economic disparities are particularly evident in the area of air pollution control. While the country of Mexico and the state of Chihuahua are in principal committed to the preservation and maintenance of clean air resources, at a practical level the degree of pollutant source control on the Mexican side of the border lags considerably behind air pollution characterization and control programs in place on the US side. The existence of sister cities on either side of the border poses special problems for those cities faced with compliance with the US and Mexican clean-air statutes. Border cities such as Tijuana-San Diego, Nuevo Laredo-Laredo, Matamoros-Brownsville and Ciudad Juarez-El Paso, to name a few, share air resources that either city has the potential to significantly alter. Such issues as trans-border pollutant flux, disparity of pollution monitoring and controls and enforcement require considerable inter-governmental cooperation and understanding, particularly in locales, such as El Paso where federal punitive measures are imposed for non-compliance with air quality regulations.

The El Paso-Cd. Juarez airshed is no exception in regard to such issues. Local, state and federal agencies have struggled for many years for a mutually satisfactory approach to the problem. The Cd. Juarez-El Paso airshed has historically exceeded US Clean Air Act National Ambient Air Quality Standards for such pollutants as PM_{10} (particles less than 10 um diameter), CO (carbon monoxide) and ozone. In an effort to address this problem, air pollution officials in the State of Texas and the City of El Paso have lobbied the US EPA for many years to provide a Federal mechanism by which air pollution characterization and control strategy development could be achieved by international cooperation in the area. In recent years, the Mexican Federal Secretariat of Social Development (SEDESOL) and its predecessor the Secretariat of Urban Development and Ecology (SEDUE) the agency that is analogous to the US EPA, has taken a more active interest in U.S-Mexico border air pollution problems. Factors such as these figured prominently in the successful negotiation and approval of the so-called Annex V that is part of the 1983 US-Mexico Border Environmental Agreement dealing in particular with air pollution issues along the US-Mexico border. Finalization of this agreement in 1989, and the appropriation of funds by the US Congress, also in 1989, laid the groundwork for a series of joint US-Mexico air pollution studies designed to more fully understand pollution sources and their impacts on both sides of the border.

Specifically, Annex V commits the US and Mexico to cooperate in the further development of air monitoring programs, pollutant emission inventories and air modeling approaches for the trans-border regions, with the ultimate purpose of assessing and implementing various pollution control strategies for the entire region.

This report summarizes much of the work that has been completed under the Annex V agreement by various regulatory agencies and research institutions. Taken as a whole, the work reviewed in this report represents a significant level of effort that has been advanced in the region over nearly 20 years. Collectively, the studies have advanced the technical knowledge from which further decisions regarding pollutant characterization and pollutant source control can be based. Many of the study efforts have also enabled productive working relationships to develop between US and Mexico counterparts in the various regulatory and research agencies.

Six major sections constitute this report. The first section, of which this paragraph is a part, introduces the topic at hand. A second section serves to briefly introduce the reader to some generalities about the El Paso-Cd. Juarez area such as local topography, climate and a brief historical perspective on regional air pollution trends over the past decade. Reviews of a number of special air pollution investigations carried out in the region by various institutions prior to 1989 are presented in Section 3. The work summarized in these reviews clearly illustrates that investigations into border air pollution issues were by no means initiated in the late 1980's. Summary results from these early investigations are presented in this report since they provide the technical basis upon which many of the later studies followed. A fourth section of the report summarizes much of the work funded by US Congressional grant monies as a part of the Annex V agreement and carried out between 1989 and 1992. These recent studies represent investigative work on both sides of the border and fill some of the information gaps revealed by those studies conducted prior to 1989. A fifth section of the report goes into considerable detail in describing a short-term, intensive, winter-season study carried out in 1990-91 to assess PM_{10} pollution levels and to investigate PM_{10} sources using receptor modeling techniques. Analytical work and conclusions drawn by the project team are discussed with a particular emphasis on their implications for understanding PM_{10} sources and pollution levels in the region. A final section of the report presents an overall summary of work accomplished along a forward look at some of the air quality issues likely to be of importance as well as discussing new technologies that may be available for further characterization and control strategy assessment of air pollution sources in the region.

2.0 Background Information

2.1 Local Topography

The local topography in the El Paso-Cd. Juarez region falls into the category of complex terrain as a result of moderately sized mountain ranges that lie both to the north and west of the central El Paso-Cd. Juarez urban area. Local elevations range from 1150 m at the river to 1850 m at the top of Franklin Peak as shown in Figure 1, a contour map of the region. A 3-D perspective view of the region with an exaggerated scale in the vertical direction, shown in Figure 2, reveals the Franklin mountains dividing suburban areas of El Paso into eastern and western halves with the downtown El Paso area lying just beyond the southern extent of the Franklins. The Rio Grande flows southward out of central New Mexico through the broad Mesilla Valley on the west side of the Franklin Mountains. At the bottom of this valley, a large obstacle, the Sierra de Cristo Rey, lies directly in the path of the river's southward course. The river bends around Cristo Rey, cuts through the pass between the Franklin and Sierra Juarez mountain ranges, courses in a generally southeasterly direction between the downtown districts of El Paso and Cd. Juarez and finally flows out into an even broader valley to the southeast. To the west of the Juarez city center lie the Juarez Mountains, rising to 1650 m above the valley floor. To the northeast of the downtown El Paso region lies the extreme southern portion of the Tularosa Basin, bordered on the east by the Sacramento Mountains and on the west by the northern reaches of the Franklin Mountains. Much of the recent suburban growth in El Paso is occurring in this northeastern portion of the city. To the south of Cd. Juarez lies the Chihuahuan Plateau characterized by relatively flat terrain, gradually increasing in altitude above the valley floor as one moves toward the south.

2.2 Local Winter-Season Climate

During winter, atmospheric stagnation conditions marked by stable air masses and low wind speeds, are often encountered in the region. These frequently observed calm conditions result in pollutant buildup over time in the stable air mass. Pollutant dilution is further minimized during the evening and early morning hours during stagnation events by the formation of radiation inversions. As the sun approaches the horizon near the evening hours, the radiant energy flux from the sun to the surface of the ground decreases, resulting in a cooling of the earth's surface by the process of radiant heat loss. During the evening hours, the earth, which is warm relative to the cool winter air aloft, radiates thermal energy to the atmosphere. Air in contact with the ground is, in turn, cooled by convective heat transfer with the cool surface. Air aloft, not in contact with the ground, experiences no significant change in temperature. The resulting state of the atmosphere is characterized by a cold ground surface, a cool air layer near the ground and an overlying relatively warm air layer. The cool air layer possesses no buoyant rise relative to the warmer air layer aloft and thus vertical mixing of the atmosphere is suppressed. A radiation inversion is enhanced by clear skies, since overlying clouds will radiate heat back to the surface and limit surface cooling. The inversion depth will characteristically build throughout the evening and early morning hours, finally dissipating when the early morning sun once again begins to heat the ground. During a radiation inversion, the air behaves much like water in the bottom of a flat valley. Cold air tends to flow into low lying areas and puddle there until forced to move by the frictional effects of overlying warmer air in motion or when solar heating of the ground occurs. In the El Paso-Cd. Juarez region, the valley is roughly a hundred meters deep below the surrounding plateau while the mountains protrude into the upper flow some 700 m above the plateau. Neither the mountains nor the valley are as simple as described--however the overall topographical picture is one that features complex mountain ridges and valleys that serve to trap airmasses thereby limiting the dispersal of pollutants.

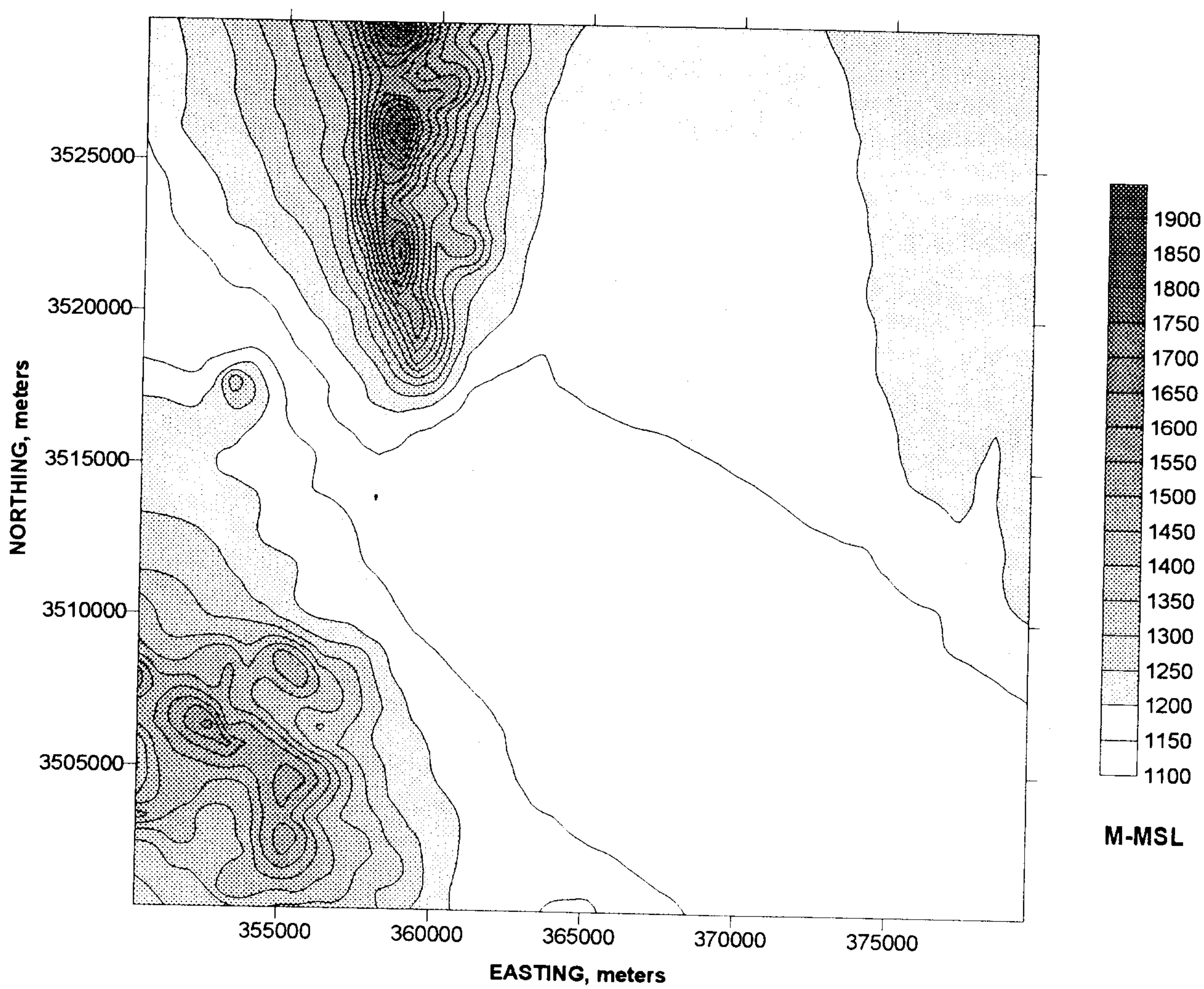


Figure 1 A contour map of the El Paso del Norte region. The grid shown is 30 km on a side and the axis units are in meters.

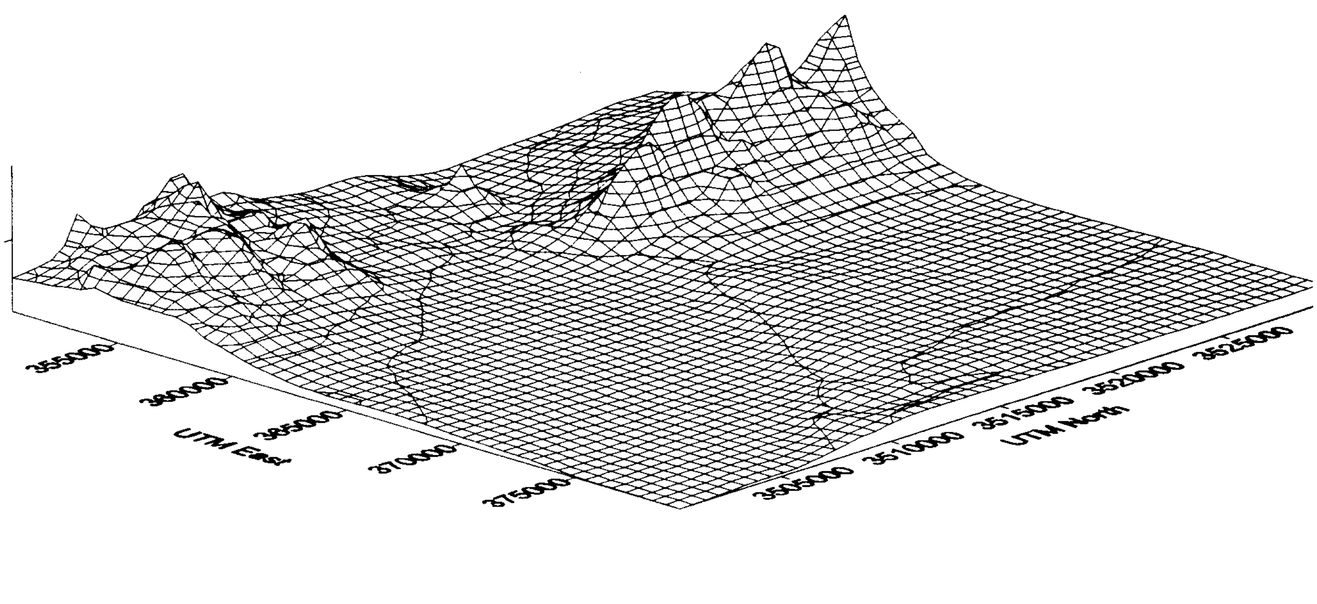


Figure 2 A perspective plot of the El Paso del Norte region as viewed from the southeast. The overall square grid domain is 30 km.

2.3 Regional Air Quality Monitoring Programs

Air quality monitoring programs have been in place within the El Paso del Norte region for many years. As a result of the original Federal Clean Air Act of 1970, funding mechanisms through the US EPA have made possible continuing development of air quality networks on the El Paso side of the border. In the early days of the program, monitoring sites usually consisted of total particulate samplers and gas sampling systems employing wet chemical techniques at a few sites. Over the past several decades the development of reliable continuous air quality monitoring instrumentation has been a key factor in the further development of air quality monitoring networks in El Paso. Currently, numerous US monitoring sites are scattered throughout the region. The coverage ranges from the Moon City clinic at the extreme southeast portion of the valley, about 25 km distant from downtown El Paso, to Las Cruces, New Mexico, 70 km to the northwest of El Paso. Monitoring capabilities require considerable cost and manpower for instrument acquisition and maintenance however, so not all sites are similarly equipped with monitoring instruments. At the present time the US monitoring sites within the region are maintained and operated by the Texas Natural Resource and Conservation Commission (TNRCC), the El Paso City-County Health Department, and the New Mexico Environment Department.

Monitoring capabilities in Cd. Juarez are less developed than those on the US side of the border. In general, the stage of development at Cd. Juarez monitoring sites is at a point similar to the condition of US sites 10 or 15 years ago. At many of the sites, the monitoring capabilities consist of a single total particulate or PM_{10} hivolume sampler. While many of the US sites are networked to a common data processing location, this is not true for Cd. Juarez sites. The operating budgets of SEDESOL, are much smaller when compared to US agency budgets and they typically do not include provisions for the purchase of relatively expensive air quality monitoring equipment. While one can convincingly argue that pollution monitoring agencies in the US are under-staffed, Mexican agencies find themselves in a comparatively worse situation significant resource limitations. As a part of the Annex V agreement however, some US funding was made available to the Mexican agencies for the modernization of the air monitoring network in Cd. Juarez. Two Cd. Juarez sites in particular were extensively developed and networked to a common data repository along with several US sites as a part of the intensive winter season particulate study carried out in Winter 1990-91 discussed in more detail in Section 5 of this report.

2.4 El Paso del Norte Airshed Pollution Historical Trends

An in-depth review of pollutant levels in the El Paso-Cd. Juarez area over the past several decades is beyond the scope of this report however, graphical summaries of the four highest PM_{10} levels and the two highest CO levels at selected sites in both Cd. Juarez and El Paso over the past decade are given in Figures 3 through 6. The PM_{10} data represented in these graphs are compiled from "quick look" summaries taken from the EPA Aerometric Information Retrieval System (AIRS) data base. Numerous exceedences above the US air quality 24-hour average PM_{10} standard of 150 $\mu g/m^3$ are observed at some of the more highly polluted monitoring sites on both sides of the border. Of interest, however, is the fact that PM_{10} pollution, as represented by the four highest readings in a year for the US sites, shows a decreasing trend, particularly in the years 1990 through 1993. Highest and second highest 8-hour averages for CO are shown that exceed the air quality standard of 9 ppmv. The CO trend for the US site, shown in Figure 4, is less clear and indicates either stable or increasing levels. Pollution trends for PM_{10} and CO data from Cd. Juarez, as shown in Figures 5 and 6, cannot be discerned since only four years of data are available in the AIRS database.

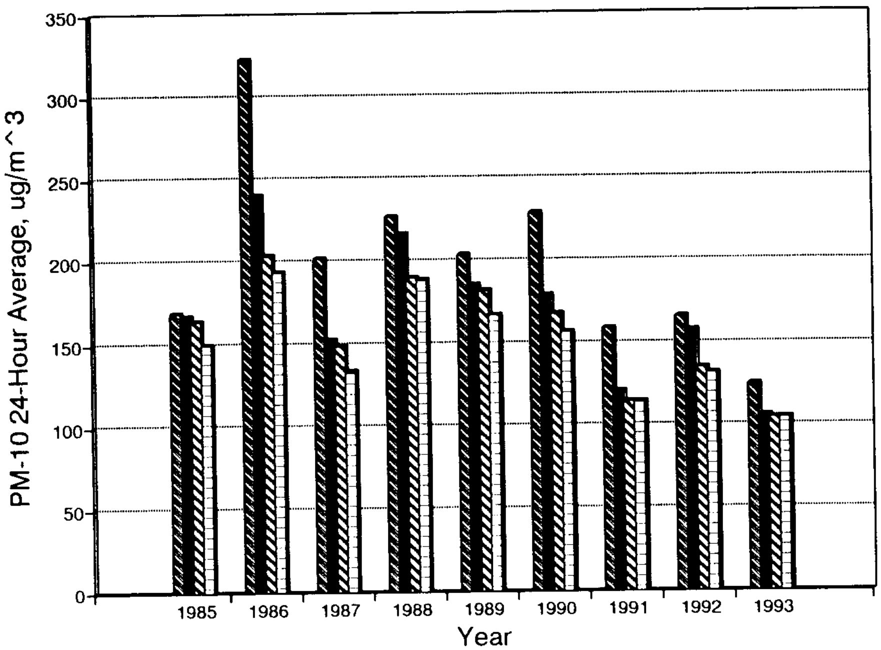


Figure 3 The four highest 24-hour PM-10 levels measured annually at the El Paso Tillman site from 1985 through 1993.

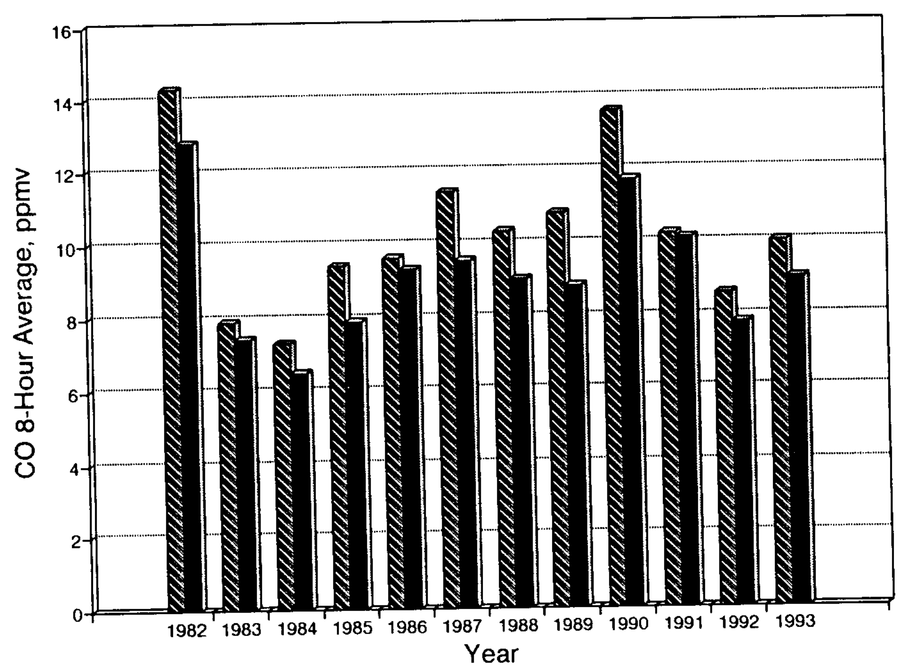


Figure 4 The two highest 8-hour CO averages measured annually at the El Paso Tillman site from 1985 through 1993.

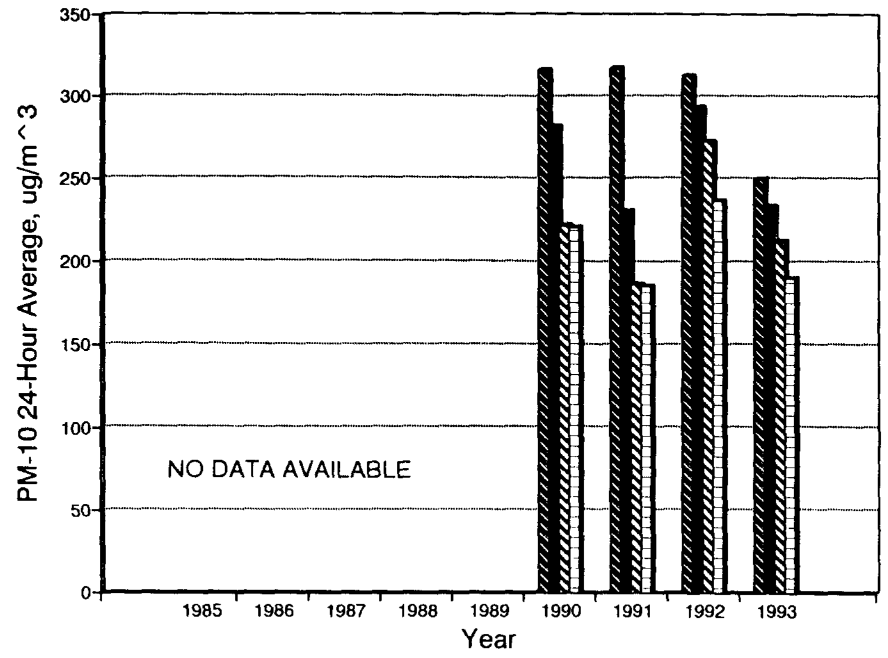


Figure 5 The four highest 24-hour PM-10 levels measured annually at the Cd. Juarez Advance Transformer site from 1990 through 1993.

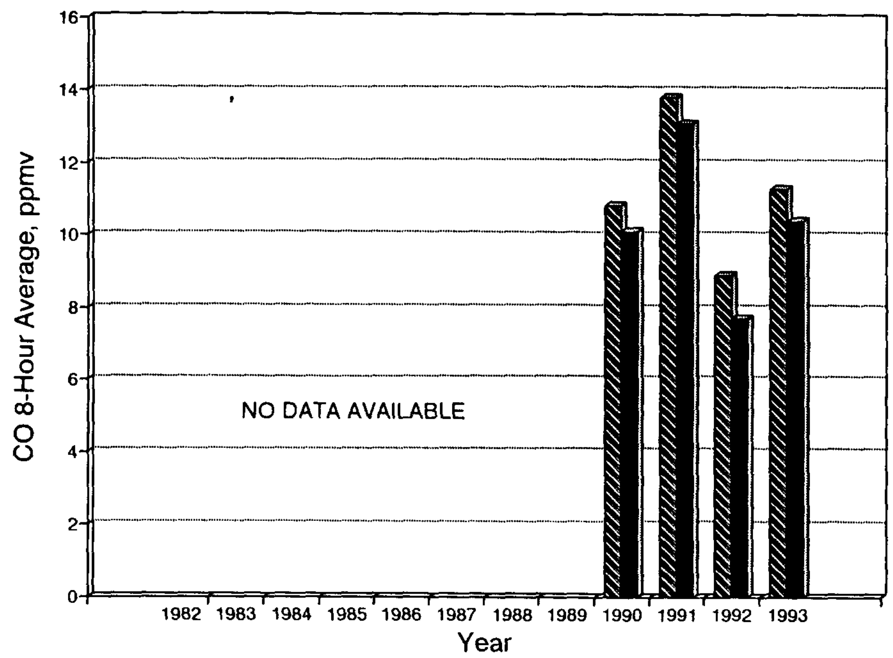


Figure 6 The two highest 8-hour CO averages measured annually at the Cd. Juarez Advance Transformer and Tecnologico sites from 1990 through 1993.

A summary of average 24-hour PM_{10} levels measured during the 1992 fourth quarter prepared by the EPA Region 6 Geographical Information Center is shown in Figure 7. Average PM_{10} data from all PM_{10} sites reporting into the AIRS data base are shown along with interpolated values over the entire region as contour lines. The highest level is near 150 $\mu g/m^3$ and is observed in central Cd. Juarez. In general, the PM_{10} contour levels show an increasing trend as one moves south from the US into Mexico.

These summary historical data illustrate that pollution levels in excess of applicable air quality standards occur with some regularity in the area. Although graphical summaries for ozone are not shown here, air quality standard exceedences are observed for this pollutant as well. Exceedences of the US NAAQS PM_{10} standard occur on both sides of the border raising many issues concerning the degree of responsibility borne by each country and the extent to which control measures need be applied in the respective US and Mexican urban areas.

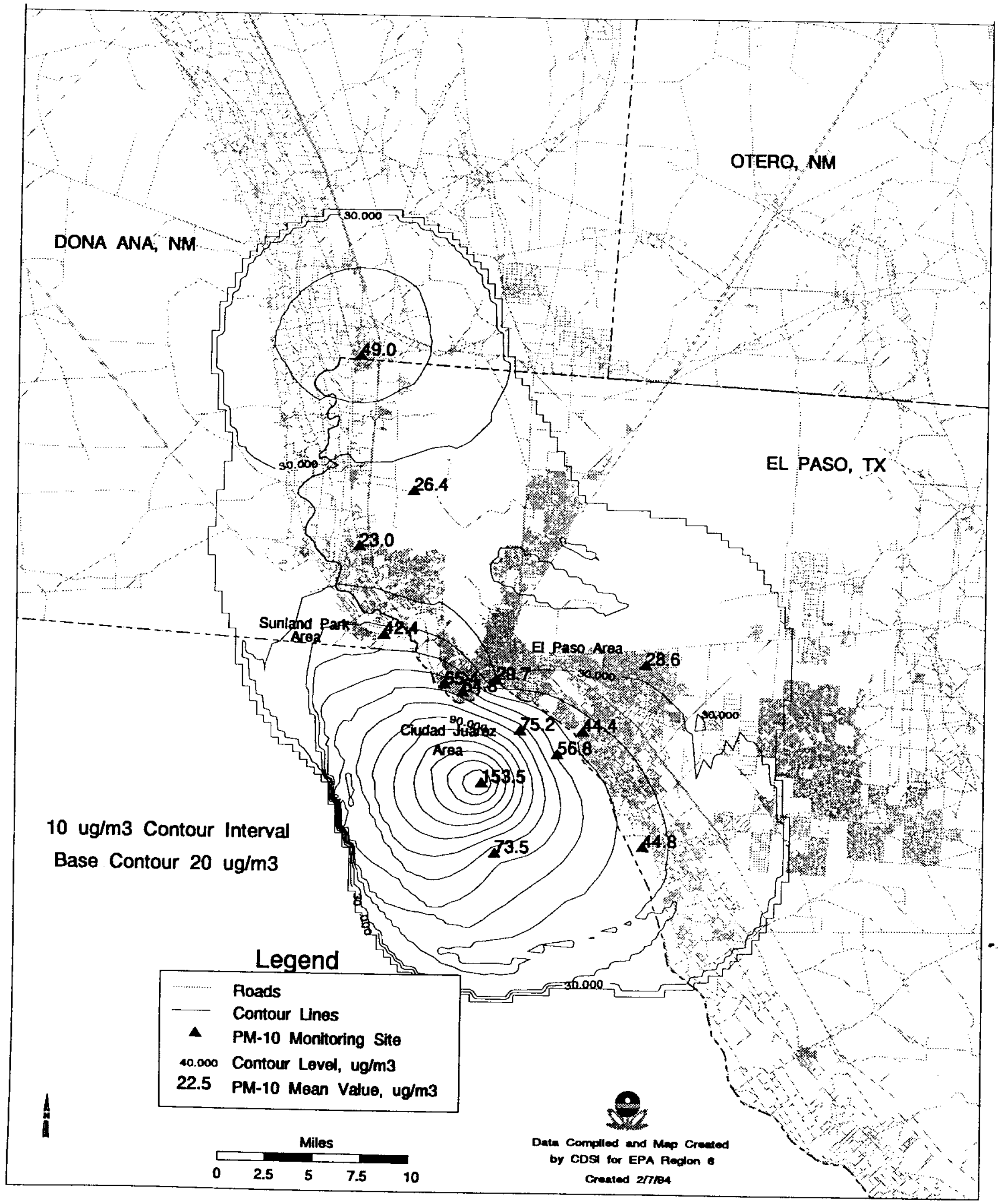


Figure 7 Fourth-quarter 1992, 24-hour average PM-10 measurements in Cd. Juarez and El Paso showing interpolated values over the region as contour lines.

3.0 Pre-1989 El Paso-Cd. Juarez Air Quality Studies

3.1 Carbon Monoxide Studies -- University of Texas at El Paso, 1983

A report published by the Center for Inter-American and Border Studies at the University of Texas at El Paso reviews a number of studies that were carried out in the early 1980's in the Cd. Juarez - El Paso region [Bath, 1983]. A cursory review of each of several chapters included in the report follows.

A brief review of topography, climatology and traffic are presented by H. G. Applegate. In this short summary, the author notes that correlation studies comparing simultaneous wind speed and direction measurements at the El Paso International Airport, local TACB monitoring sites and Cd. Juarez Aeropuerto Federal failed to show any correlation among the various sites.

M. Aguirre and others summarize various local and Federal air quality standards enacted at the time when this report was published along with a description of various measured CO exceedences and the meteorology associated with them. The authors note that El Paso was determined to be out of compliance for both CO and O_3 federal air quality standards.

Price and Applegate present a discussion of international bridge crossings along with estimates of CO release from vehicles crossing the bridges based on estimates of CO emissions from US cars. The authors did not attempt to estimate the CO emission levels from many older, poorly maintained Mexican vehicles but rather applied US vehicle emission factors thus very likely underestimating the amount of CO from the Mexican vehicle fleet.

Olmstead reports on predictions of CO levels near the University of Texas at El Paso using the CALINE 3 Dispersion Model. The results of this particular study reveal that violations of the NAAQS for CO (35 ppm one-hour average) were not to be expected at any of five intersections surrounding UTEP for the period 1982 - 1990. The highest predicted concentration (16.8 ppm at the Mesa-University intersection) was less than 50% of the one-hour standard.

Applegate reports on the history of CO measurements in El Paso prior to 1980. An initial study was carried out by Tillman in 1959. This effort was followed by studies in 1968 at San Jacinto Plaza and in 1973 at the Americas and International Bridges.

Reynoso and Gonzales report on a region-wide CO grab sampling study conducted in November of 1981. Grab samples of urban air were collected by volunteers at numerous sites throughout the region at precisely the same time. Samples were subsequently analyzed for CO content by a portable sampler. CO "hot spots" were observed along a corridor extending from east of downtown Cd. Juarez in a northerly direction to a point east of downtown El Paso. The International Bridge was also located in this corridor. Mean CO values throughout both cities were 13, 15 and 11 ppm at 1800, 2000 and 2200 hours respectively.

McDonald and Rab report on CO in the vicinity of Fort Bliss. The authors note the formation of a rideshare program to reduce CO emissions in this particular area of El Paso.

Quiz reports on CO concentrations in Cd. Juarez (written in Spanish).

3.2 Inhalable Particulate Matter Assessment -- Environmental Research and Technology Inc., 1983

The Texas Air Control Board commissioned Environmental Research and Technology Inc. to conduct a study to assist the agency in an assessment of the significance of primary particulate matter emissions in the PM_{10} and PM_{15} size ranges in the Houston-Galveston and El Paso areas [ERT, 1983]. The study was carried out prior to the enactment of a PM_{10} or PM_{15} standard for airborne particulate matter and was intended to investigate how the new standard might impact these two urban areas. The primary tasks carried out during this study are briefly summarized below.

> Identify the major stationary sources of primary particulate matter in the Houston-Galveston and El Paso areas and determine the extent to which these sources contribute to PM_{10} and PM_{15} emissions.
>
> Categorize and characterize the emissions of certain sources identified in the first task with respect to such qualities as size distribution, chemical and elemental composition, control devices in use etc.
>
> Review selected source categories to determine physiologically significant properties of PM_{10} and PM_{15} that might serve as appropriate bases for alternate regulatory standards
>
> Identify and evaluate the effectiveness of control technologies currently available for PM_{10} and PM_{15} emissions from the major source categories.
>
> Determine the cost effectiveness of the various available particulate matter control systems along with estimates of emissions reductions likely to result from the application of these technologies.
>
> Review and evaluate the effects of PM_{10} and PM_{15} emissions on ambient air quality with an intent to identify gaps in the current level of understanding and to suggest additional studies to fill these information gaps.

In the interest of brevity only a few salient points, most relevant to the current issues faced in the El Paso-Cd. Juarez airshed, are summarized from this broad effort.

> The study examined emissions from only those stationary sources compiled into the TACB 1980 emissions inventory. Based on this inventory, stationary sources accounted for 15% of the total emitted particulate matter in the El Paso area and 55% of the total in the Houston-Galveston area.
>
> Thirty-nine source categories are listed for the El Paso region as compiled from the TACB 1980 Emission Inventory. Most of these are related to non-ferrous (copper, lead, zinc) metal production, cement production and petroleum refining operations. The two highest non-fugitive point source categories were copper reverberatory furnaces at 107 tons of PM_{10} per year and fluid catalytic crackers at 108 tons per year.
>
> The study produced an estimate of the degree to which overall PM_{15} emissions would be reduced if all non-fugitive point sources were eliminated. For the case of El Paso, a total reduction of 6% was determined. In contrast, a PM_{15} reduction of 25 to 37% was estimated for the Houston-Galveston area. The authors note however, that no attempt was made to take sources in either Mexico or New Mexico into account in these estimates.

The authors speculate that based on limited PM_{15} measurements completed at the time of the study, exceedences of a likely 24-hour average PM_{10} standard in the range of 55-120 $\mu g/m^3$ would not be expected to occur.

The authors also point out the need for the chemical and physical speciation of ambient air samples to provide appropriate data for the application and use of receptor models which they suggest would help to quantify the contributions of various source types to the overall PM_{10} in the region.

3.3 Air Quality Database Study -- Radian Corporation, 1983

A study was commissioned by the Texas Air Control Board in the early 1980's to describe El Paso air quality and to identify significant pollution sources. A database for selected pollutants and meteorological parameters was compiled for use in the study from sampling networks, on the US side of the border only, operated by TACB, EPCCHD, NMEID, NWS and ASARCO over the years 1977 through 1981. Specific pollutants investigated were TSP, CO, SO_2 and Pb. The database drew from 22 TSP monitoring sites, 17 Pb sites, 10 SO_2 sites and four CO sites and included quality assurance criteria for all pollutant and meteorological parameters accepted into the database. The study is segmented into two volumes, the first [Radian, 1983A] presents analyses results and conclusions and the second [Radian, 1983B] presents the data validation criteria used for compilation of the database.

The authors of the study conclude that exceedences of national ambient air quality standards for TSP, CO and Pb occurred during the study interval. Sulfur dioxide was not observed to exceed the standard however values close to the standard were observed.

Some of the more important conclusions from this study are summarized as follows:

One-hour CO exceedences were not observed at any sites however the 8-hour CO standard was exceeded at three of the four sites used in the study. Eight-hour CO averages exceeded the 9 ppm standard less than 1 percent of the time for three of the four sites. Peak 8-hour levels at these same three sites averaged 10.9 ppm.

High TSP levels in El Paso are associated with dry conditions which favor the re-suspension of urban or rural particulate material. Monitoring data show that high winds can increase TSP levels as a result of entrainment of material from exposed soil. High TSP levels were recorded on so-called "dust storm" days as well as on days characterized with moderate or light wind speeds.

The most important sources of TSP in El Paso are re-suspension of local particulate matter by urban traffic and by winds gusting over 15-20 mph. These situations produce at least 50 to 80 percent of the measured TSP at most monitoring sites as indicated by a companion microscopy study discussed in a following section of this report.

Sources of lead emission that contribute to high ambient lead levels include transportation sources using leaded gasoline, ASARCO smelter emissions, and re-suspension of lead-containing particles by wind or vehicles. Lead levels are observed to be highest during periods of air stagnation in the region.

As a part of this study, meteorological conditions were reviewed for days on which high and low TSP measurements were observed. High TSP days were classified as days on which at least one site recorded its highest reading for the period 1979-1981. An analogous approach was taken to identify a collection of low TSP days. The authors observe that peak sustained winds in excess of 20 mph were reported on six of 16 "high" TSP days encountered in the period 1979-1981. Winds of 11-20 mph were recorded on another six of the days with the remaining four days having peak wind speeds less than 10 mph. The daily resultant wind directions did not show any consistent patterns for the high TSP days leading the authors to conjecture that non-local sources of TSP accounted for the measured levels.

The authors go on to point out that most of the low TSP days were characterized by rainfall occurring within the previous two days of the measured level. Nine of the 12 low TSP days had rain on the same day or during the preceding two days. Ten of the 12 days had moderate wind speeds with peak sustained winds from 11-20 mph.

A correlation study of so-called "persistent wind" days with TSP concentration was also conducted in this study. Persistent wind days were classified as those days in which the ratio of resultant wind speed (the vector average) to mean wind speed was 0.7 or greater. The authors conclude that for the sites investigated on days with the wind blowing from a persistent direction, there was no significant dependencies of measured TSP on wind direction. These results are taken to suggest TSP originated from either multiple local sources or a regional source.

Finally, the authors note that the statistical analyses carried out on the database do not resolve the question of the relative contributions to high pollution levels made by sources in El Paso and Cd. Juarez. The absence of any clear correlations of TSP with wind direction is taken to suggest that Cd. Juarez is not necessarily the predominate source of TSP.

3.4 El Paso Quantitative Microscopy Study -- Energy Technology Consultants, 1983

Another study was commissioned by the Texas Air Control Board in parallel with the Radian Air Quality Database Study. This study, known as the El Paso Quantitative Microscopy Study, was conducted by Energy Technology Consultants with a goal of identifying and quantifying the sources of TSP and particulate lead in the El Paso airshed using a combination of microscopy analysis and a receptor modeling approach. The report is organized into two volumes with the first [Energy Technology Consultants, 1983A], giving analysis results and conclusions, and the second [Energy Technology Consultants, 1983B] presenting the analytical methods in detail along with quality assurance procedures and results of statistical analyses.

For this study, a number of ambient TSP samples collected during 1981 were selected from archives for detailed analysis using a computer controlled scanning electron microscopy-energy dispersive x-ray method. The study incorporated receptor modeling techniques to the extent that source contributions were inferred from the elemental content of particulate material on the filters subjected to analysis. A total of 70 ambient TSP samples on cellulose or glass filters were selected from six monitoring sites to represent air quality in El Paso. Filters were selected to correspond to low TSP ($< 59\ \mu g/m^3$) mid TSP ($59 - 125\ \mu g/m^3$) and high TSP ($>125\ \mu g/m^3$) occurrences. In the analysis an emphasis was placed on the high TSP samples in an effort to identify sources contributing to exceedences of the air quality standards.

A number of bulk soil, industrial particle, and vehicular emission samples were also collected in the El Paso area and were analyzed with the same apparatus as used for the filter samples. The samples were used to quantitatively describe known major sources of particulate material in the

El Paso airshed and were the references against which the filter sample results were compared using receptor modeling techniques. Analyses of numerous soil samples resulted in considerable overlap of the fingerprints of each sample. To simplify the source profile, the following general source categories were defined:

Soil - a blend of the various soils encountered in El Paso

Industrial Fugitives - emissions from brick manufacturing, rock quarrying, slag crushing, and cement operations

Highway - exhaust emissions from lead fueled vehicles along with entrained soil, road wear and tire wear particles

Smelter - various fugitive and stack emissions from the ASARCO primary lead and copper smelter

Unknown - material for which no fingerprint could be found (this source classification likely includes emissions from various Mexican sources not measured in the study)

Table 1 summarizes the TSP source apportionment results from this study using the computer controlled scanning electron microscopy method for seven sites throughout the El Paso city area. These summary results reveal that urban soil contributes in the range of 50 - 85% of the total TSP on the filters at all sites surveyed in the study. The next highest category is Industrial Fugitives followed by the Highway category.

The authors compared receptor modeling results obtained by microscopic analysis to receptor modeling results carried out by Radian Corporation and the Texas Air Control Board using elemental tracer techniques and found good agreement between all three approaches for a site near the ASARCO smelter.

Table 1
Fingerprint/Ratio Source Apportionment Results for TSP at Various Monitors in El Paso

Site Location	Direction & Distance (km) relative to ASARCO		Ave TSP μg/m³	Number of Samples	Urban Soil (%)	Industrial Fugitive (%)	Highway (%)	Smelter (%)	Unknown (%)
Tillman, TACB	SE	4.8	131	10	52	19	11	8	10
Tillman, EPCCHD	SE	4.8	147	9	56	16	13	6	9
UTEP	E	1.61	76	4	60	14	8	9	9
Ascarate Pk	ESE	11.2	80	4	85	3	8	3	3
IB&WC	WNW	0.3	311	12	47	23	2	21	7
Zack White School (NM)	NW	6.4	918	8	78	9	3	3	8
Ivanhoe	E	20.9	78	8	57	5	17	4	17

from [Energy Technology Corporation, 1983A]

4.0 Regional Studies Conducted after 1988

4.1 Airborne Lidar Study -- EPA Environmental Monitoring Systems Laboratory, 1989

Region 6 EPA commissioned the EPA Environmental Monitoring Systems Laboratory to conduct an airborne lidar study of the El Paso-Cd. Juarez area in February 1989 [McElroy, 1990]. The objectives of the study were three-fold and are summarized as follows:

> Develop an aerometric database in order to ascertain the spatial extent and magnitude of the suspended particulate problem in the El Paso-Cd. Juarez region.
>
> Plan a comprehensive monitoring program to aid in the development of pollution attainment strategies in the El Paso-Cd. Juarez region. This study was carried out preliminary to an intensive ground-based PM_{10} monitoring study that is described in a later section of this report. Information from this study was used in the selection of numerous PM_{10} monitoring sites.
>
> Determine, if possible, the magnitude and direction of particulate pollution flux across the international boundary between the cities of El Paso and Cd. Juarez.

The principal feature of this study was the deployment of a downward-looking airborne lidar system used to map aerosol in the region on both sides of the border by measuring the aerosol backscattered intensity of laser pulses from the lidar. The lidar system measured backscatter intensity from a light pulse as a function of time after exiting the lidar. The elapsed time during which the laser pulse travels out and is scattered back from a distant aerosol mass to the lidar is a measure of the aerosol mass distance from the lidar. Lidar pulse rates for this particular system were between 1 and 10 per second. Since the aircraft is also moving forward as the laser is continuously pulsed, a two dimensional picture of aerosol burden in the area can be produced during a single aircraft pass over an area. By flying multiple parallel passes over an area during a several-hour period, a three dimensional picture of aerosol concentration in the area can be produced.

The airborne lidar phase of the study was supplemented by a number of ground-based measurement systems including nephelometers and stacked filter units (measuring 2-hour intervals of fine and coarse aerosol concentrations) at three sites along the international border. These measurement systems were included to yield ground-truth data with which to compare the lidar aerosol density measurements. Winds aloft were also measured during aircraft flyovers with two radiotheodilite stations in the region as well. Continuous PM_{10} data available from several beta gauge monitors positioned on the rooftop of the Tillman Health Center in downtown El Paso were also used for comparison with aerosol density measurements made with the airborne lidar.

The authors prepared a series of contour plots of lidar backscatter intensity averaged in the altitude interval ranging from about 6 to 40 m above the ground over the entire region by use of interpolation routines that estimated lidar backscatter in the regions between those for which overflights were completed. Figure 8 is a typical example showing data for the morning of February 23. The actual flight tracks over the region are noted by plotted circles. The contour lines resulting from the data interpolation routine are shown as solid lines. Contour units are given as aerosol backscatter intensity--a parameter which is roughly correlated to aerosol density. The highest aerosol levels are observed along both sides of the international border and in particular near the downtown areas of both cities. High levels are also noted near the smelter located close to the junction of the Texas, New Mexico and Mexico border. The highest aerosol levels in the study were observed in the vicinity of a burning refuse dump located in the foothills of the Juarez Mountains southwest of the El Paso city center.

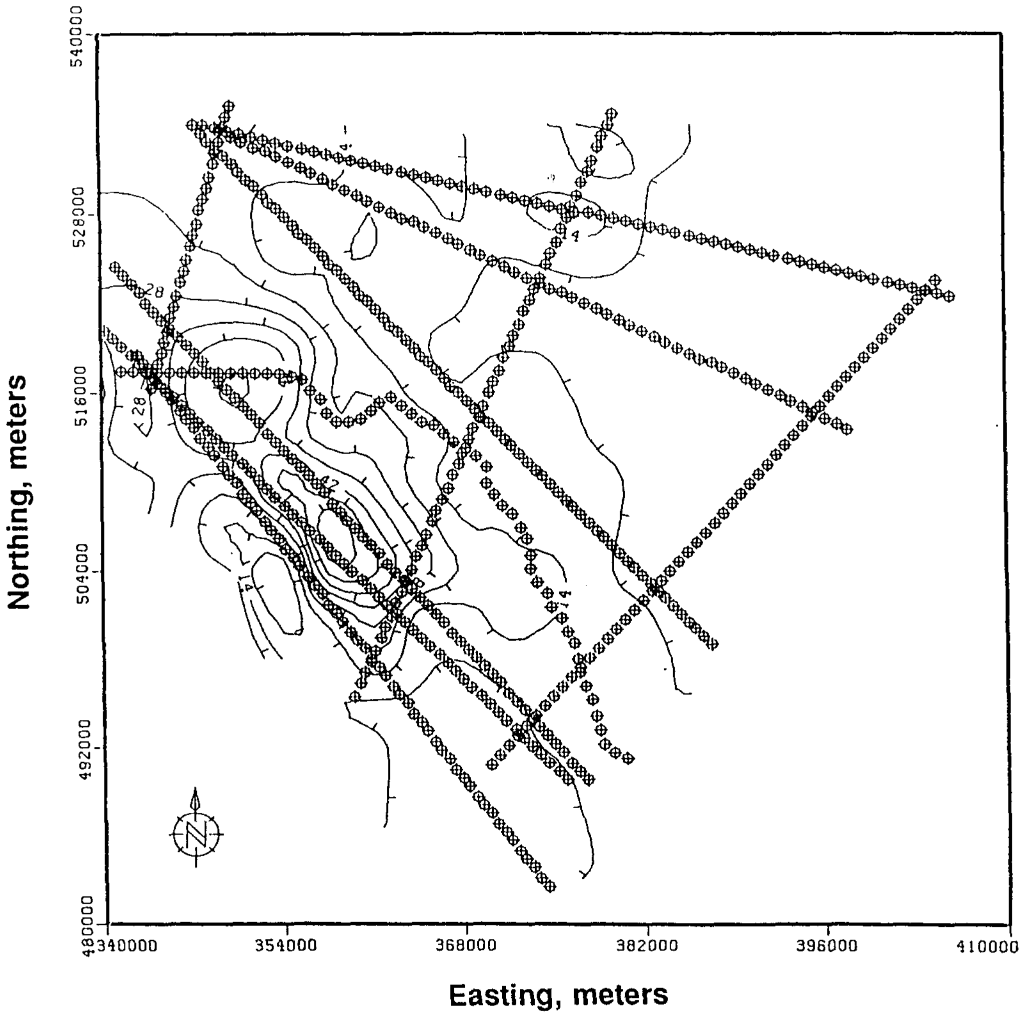


Figure 8 A graph showing airborne flight tracks (circles) on the morning of February 23 with near ground-level aerosol backscatter intensity, interpolated from the lidar data, shown as contour lines [from McElroy, 1990].

The authors further discuss the results of several attempts to relate lidar backscatter measurements to measured ground-level aerosol concentrations. First, the lidar backscatter intensity measured in the vicinity of the three ground-level sites, where aerosol monitoring equipment was positioned, were compared in an effort to convert lidar backscatter intensity values to aerosol density. The authors report that although some parameters showed a reasonable relationship to lidar data, in general, the relationships between ground-based aerosol concentration measurements and lidar backscatter measurements at the same locations were inconsistent from site to site. The authors go on to discuss a number of factors which may mask the observation of clear relationships between lidar backscatter intensity and ground-level aerosol concentration. First, the lidar data collection flight tracks were not flown directly over the sampling sites where aerosol concentration measurements were being made, thus, different volumes of air may have been compared by the two methods. Second, ground reflection of the lidar pulse interferes with the measurement of aerosol closest to the ground which is what the ground-level samplers are measuring. Finally, the filter sampling interval at the ground locations was 2 hours. This relatively short sampling period resulted in light mass loadings of material on the filters, causing relatively high uncertainties in the mass concentration measurements derived from the filters. Furthermore, filter analysis was not carried out until several months had elapsed such that artifact formation or volatile losses may have occurred on the filters in the intervening storage interval. Thus, data uncertainties related to the measurement location, interval and the storage time prior to analysis may have contributed to the difficulty in seeing a clearer relationship between lidar backscatter and ground-based aerosol measurement.

In a review of data from CO and PM_{10} ground monitors, the authors note considerable temporal correlation between the two parameters. Based on these observations, the authors suggest that CO may be a reliable predictor of PM_{10}. The authors go on to suggest that three lidar flights occurring at about 8 AM, 2 PM and 8 PM would yield enough data to give a reasonable prediction of 24-hour CO and PM_{10} levels encountered on any particular day.

As a part of this study, elemental analysis was carried out on a series of stacked filter units that were sampled over a 2-hour interval on various days during the study. The average mass breakdown of the fine aerosol fraction (< 2.5 micrometer diameter) for the Chamizal site was as follows: organic carbon, 40.3%; elemental carbon, 25.1%; sulfate species, 18.2%; crustal or soil species, 12.8%; and other, 3.5%. The authors conclude that particulate sources in the El Paso-Cd. Juarez area produce an extraordinary amount of organic particulate matter for transport and dispersion in the region. The authors do not report a similar species breakdown of the coarse fraction filters.

Finally, to address the topic of aerosol flux across the border, the authors explored the use of a diagnostic wind field model to construct a wind field of the region during selected intervals when lidar data from aircraft overflights was also available. The two data sets (wind speed and direction and lidar backscatter intensity, both as a function of position) for each lidar flight track were then combined to arrive at an average aerosol flux value for a particular flight track across the region. Results from these efforts were inconclusive. The authors note the complexity of this exploratory effort and observe that additional work would be necessary to more fully understand the relationship between aerosol density, the wind field in this complex terrain and ultimately, the flux of aerosol across the border.

4.2 Upper Air Winds and Visibility Study -- University of Texas at El Paso, 1989

Researchers at UTEP were engaged by EPA Region 6 to support the airborne lidar and saturation PM_{10} studies carried out in El Paso-Cd. Juarez in late 1989 [McDonald, 1990 and Ballard, 1990]. Measurements were carried out concurrently with the EPA-EMSL airborne lidar measurements and consisted of a tethered balloon system carrying a suite of meteorological sensors, a ground-based meteorological monitoring system and a camera for visibility degradation assessment.

Measurements were taken with these systems at the Chamizal site, located southeast of the El Paso downtown area immediately adjacent to the border, and at the UTEP campus located to the northwest of downtown El Paso at a higher elevation. Atmospheric sounding and ground based nephelometer measurements are reported for December 9 and 10, 1989.

Not surprisingly, the tethersonde data revealed temperature inversions in the early morning hours extending up to at least 150 meters. Data above 150 meters were unavailable since FAA regulations prohibit balloon flights above this altitude. The inversions were observed to dissipate as the day progressed.

Of particular interest in this study was the deployment of a balloon-borne nephelometer at the Chamizal site which allowed an indirect measurement of aerosol burden in the vertical dimension. These data were collected in order to yield "ground-truth" data for comparison with airborne lidar data collected at the same time. The report contains a selection of plots which show the measured scattering coefficient and the balloon altitude as a function of time on selected sampling days. In general, aerosol light scattering values are highest near the ground and drop off with increasing altitude. Not enough data are presented in the report, however, to assess the extent to which aerosol layers aloft were present in the 150 meter interval that the tethersonde system was flown. The authors attribute some of the high aerosol scattering measured at the Chamizal site to local activity caused by study participants. In general, aerosol scattering values 30-150 m above the ground were a factor of two or less than those measured in the region zero to 20 m above the ground.

In a companion report, researchers from UTEP describe a series of measurements made with a video camera which was equipped with a video frame grabber and software that enabled digital processing of various images taken from the UTEP campus looking toward the south over the city of Juarez. The objective of this effort was to calculate total light extinction and corresponding visual range in a semi-continuous manner over selected days in the study period. The authors describe in considerable detail the theoretical basis for how extinction values are determined from the video images. Path averaged transmittance, path averaged extinction and visibility are summarized in a series of tables for a selection of video images taken on December 10, 1989. With this technique, the authors note that the measurements are useful when compared against each other, however, estimates of visibility parameters such as extinction may not necessarily correspond to actual values present in the atmosphere when the measurements were taken. The authors note that in future studies, the use of targets with well-defined optical characteristics would enable more accurate measurements of visibility parameters. The authors make no attempt to further interpret these data with regard to time dependance or meteorological effects on the measured haze parameters.

4.3 Saturation PM_{10} Study -- EPA Region 6, 1989

An intensive short-term study of PM_{10} levels in the El Paso region was carried out by EPA Region 6 personnel in December 1989 [Kemp, 1990]. Objectives of this study were as follows:

> Integrate reference PM_{10} methods with other non-reference, short-term PM_{10} monitoring methods to characterize PM_{10} levels along the US-Mexican border and answer the following questions: (1) What are PM_{10} concentrations in regions of the airshed that are not routinely monitored? (2) Is the current reference PM_{10} monitoring network in El Paso adequately characterizing the ambient air?
>
> Develop guidelines and study protocols for the operation of portable or screening type PM_{10} monitoring in future short-term intensive studies of this nature.

Establish working relationships and foundations for future joint air quality studies between US and Mexican local and federal agencies.

The miniaturized PM_{10} monitor consists of a small battery-operated pump and filter that is equipped with a size selective inlet such that only particles less than 10 micrometer diameter are passed through the inlet and onto the filter. The filter is weighed prior to and following sampling to measure the particulate mass collected on the filter during the passage of a known volume of air through the filter. Twenty-eight of these samplers were hung from utility poles in a gridded pattern along the US-Mexico border with 24 samplers located in El Paso and four located in Juarez. Sampling intervals were either of 3.5 hours or 22 hours duration. Hourly surface meteorological data were also archived from two TACB monitoring sites (Ascarate Park and UTEP) such that a wind back-trajectory calculation could be carried out for some of the aerosol data collection periods.

Measured PM_{10} concentrations from 8:30 PM until midnight on December 9, 1989 ranged from a low of 24 $\mu g/m^3$ in the vicinity of Sunland Park, NM near the Texas-New Mexico border to a high of 745 $\mu g/m^3$ in the western area of Juarez. PM_{10} levels in the eastern portion of the basin were at about 90 $\mu g/m^3$. The authors note that the high levels in western Juarez were a result of local sources in the area. During some sampling periods, problems were encountered with the nickel-cadmium batteries used to power the saturation PM_{10} monitors. Internal battery resistance increased to high levels at temperatures near freezing such that sampler performance was impaired. Despite these problems, data capture on selected days was good and provided a data set suitable for subsequent analysis.

The 22-hour samples afforded enough sampling points on selected days to carry out data interpolation and contour mapping of estimated concentrations across the entire airshed. A contour plot showing estimated PM_{10} levels is shown in Figure 9, compiled from all 22-hour measurements taken on December 11, 1989. The highest levels are noted immediately south of the junction of the New Mexico, Texas, Mexico border. In general, the contour results for most days sampled show that PM_{10} levels are highest on the Juarez side of the border, however, as noted above, only four samplers were positioned on the Mexican side of the border.

Wind direction back-trajectories were calculated from two TACB meteorological ground stations using 10-m tower data from several days to elucidate possible sources of PM_{10} in the region. On December 12, 1989, winds were generally flowing from the west and down valley near the UTEP location where relatively high PM_{10} concentrations were observed. Sources along the western edge of El Paso and Juarez are implicated in this analysis. On the other hand, back trajectories for Ascarate Park where only moderate PM_{10} levels were observed showed motion largely confined to the eastern portion of the airshed. From these data, the authors concluded that the major PM_{10} sources exist in the western portion of the basin. The authors also note that significant differences in PM_{10} levels occur at different altitudes in the same general region of the city. PM_{10} levels in the range of 200 to 300 $\mu g/m^3$ were observed in the valley bottom just southeast of the pass while levels of about 60 $\mu g/m^3$ were observed at the UTEP site, 1.6 km distant and 44 m higher than the valley bottom sites.

The authors draw the following overall conclusions from this saturation PM_{10} study:

High PM_{10} levels were encountered regularly along both sides of the US-Mexico border in regions not normally covered by the local PM_{10} monitoring network.

The existing PM_{10} monitoring network is judged to be of marginal use for characterization of PM_{10} over the entire airshed. Very high levels near the pass at the La Hacienda

Restaurant are not adequately represented by any of the existing monitors in the PM_{10} network.

The Saturation PM_{10} Study was useful in establishing a working relationship with Mexican counterparts and will lead the way for additional cooperation between the US and Mexican agencies in the pursuit of regional air quality improvement.

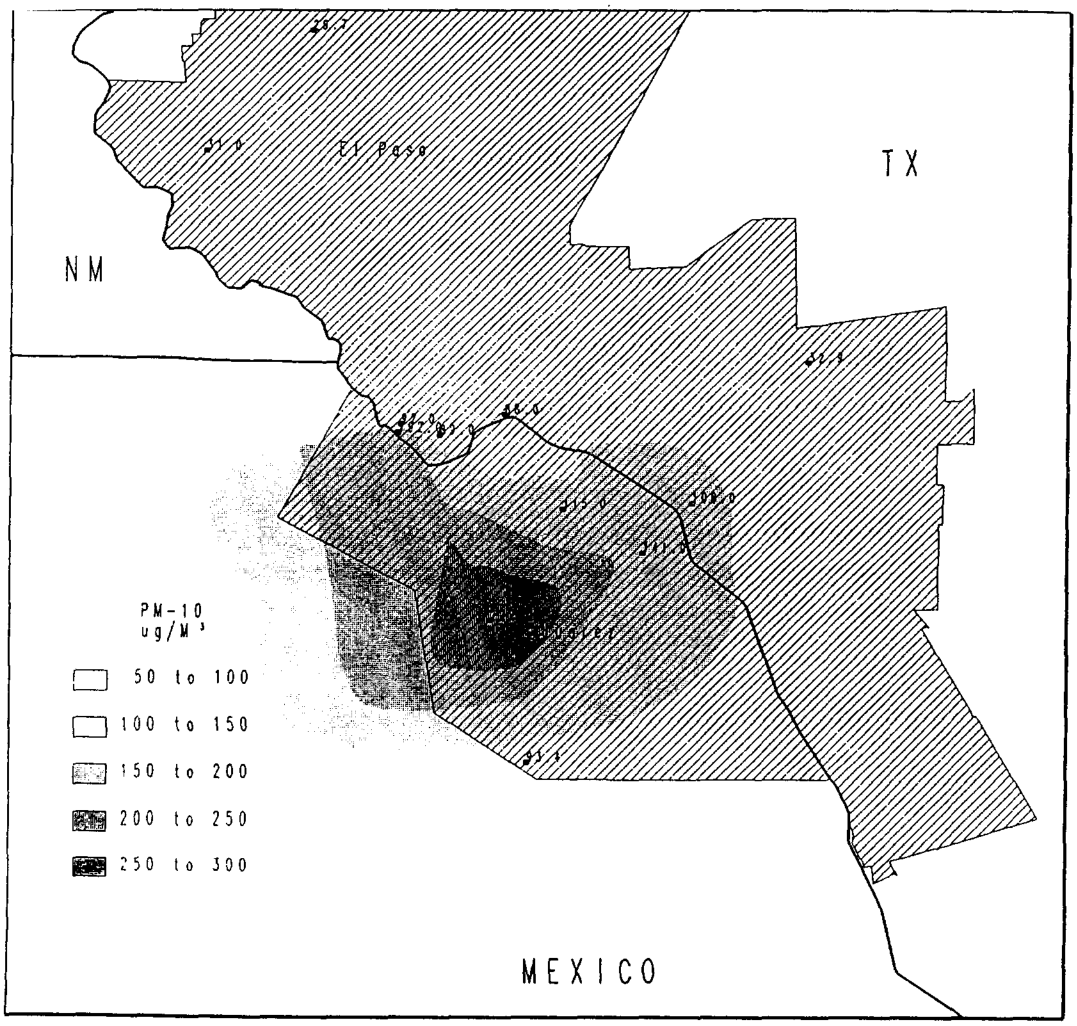


Figure 9 A contour plot showing PM-10 values interpolated from measurements on December 11, 1989 during the Saturation PM-10 Study [from Kemp, 1990].

4.4 Cd. Juarez Gasoline Vapor Pressure Study -- SEDESOL and others, 1990

In September 1990, personnel from SEDESOL, the City of Juarez, EPA and the City of El Paso collected about 40 gasoline samples from a number of gas stations in Cd. Juarez for fuel volatility measurements. Figure 10 is a histogram showing the distribution of vapor pressure readings from all samples.

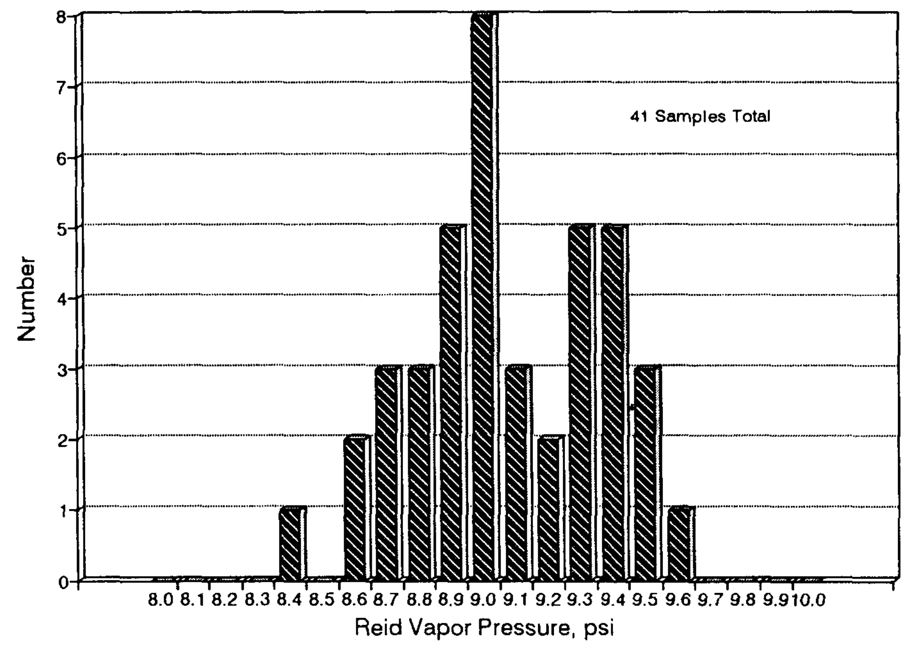


Figure 10 Frequency histogram showing RVP measurements for 41 samples collected in Cd. Juarez [from Yarbrough, 1994].

The average reid vapor pressure (RVP) value for the Cd. Juarez samples was 9.02 psi with a standard deviation of 0.29. This average was higher than an average RVP value of about 8.0 psi currently encountered in El Paso. During the mid- to late-1980's, RVP values in some Texas cities remained quite high (over 10 psi). In light of this information, it was suspected that values in Cd. Juarez would be similarly high. These survey results reveal a lower RVP value than anticipated. Consequently, VOC emissions from Cd. Juarez vehicles are expected to be lower than estimates made prior to this study.

4.5 Juarez Vehicle Tampering Survey -- Colorado State University, 1990

In conjunction with other elements of the region-wide study in 1989 and 1990, EPA Region 6 commissioned a study group from Colorado State University to conduct a tampering survey of the vehicular fleet in Cd. Juarez [CSU, 1990]. About 800 vehicles were surveyed between September

24 and October 4, 1990 at nine locations in Cd. Juarez. Two of these sites were located at the international bridges. Data collected during the survey included tailpipe measurements of hydrocarbon and CO emissions, results from visual inspection of various emissions control components and odometer readings of the surveyed vehicles. A summary of overall results, showing the degree of vehicle tampering is given in Table 2. Of the 514 light duty vehicles surveyed, 318 or 62% showed signs of tampering. An additional 75 vehicles or 15% of the total were placed in an "arguable" category where evidence of tampering was observed although inconclusive. Light and heavy duty trucks show similar high rates of tampering with rates in excess of 67% for light duty trucks and 74% for heavy duty trucks observed in the survey. In the survey report, results are further broken down into such tampering categories as catalytic converter, filler neck restrictor, air pump system, evaporative canister, exhaust gas recirculation system, heated air intake system and oxygen sensor. The highest three categories of tampering were observed in the air pump system (46%), air pump belt (44%) and catalytic converter/evaporative canister (both at 36%) categories. The authors make a comparison between tampering rates factored into the EPA Mobile4 vehicular source emission model and observed Cd. Juarez tampering rates and conclude that MOBILE4 significantly under predicts the degree of tampering expected in a fleet composition such as encountered in Cd. Juarez. For example, at the actual mileage of the Juarez vehicular fleet, MOBILE4 predicts a tampering rate of 37.9% as compared to an observed rate of 67.2%. In light of these uncertainties, the authors point out that MOBILE4 in turn would underestimate the true Juarez vehicular fleet exhaust emissions.

Table 2
Juarez Vehicular Fleet
Tampering Survey Summary Statistics

Vehicle Type	Condition	Count	Rate
Light Duty Vehicle	Pass	107	21%
	Malfunction	14	3%
	Arguable	75	15%
	Tampered	318	62%
Total		514	
Light Duty Truck	Pass	52	20%
	Malfunction	11	4%
	Arguable	22	8%
	Tampered	175	67%
Total		260	
Heavy Duty Vehicle	Pass	3	6%
	Arguable	11	20%
	Tampered	40	74%
Total		54	

from [CSU, 1990]

4.6 Cd. Juarez Emissions Inventory -- Alliance Technologies and others, 1990

Beginning in 1990, EPA-Region 6 worked with SEDUE, SEDESOL's predecessor, to improve the industrial emissions inventory for Cd. Juarez. A contract was placed with Alliance Technologies Inc. to develop an emissions inventory questionnaire for distribution to Cd. Juarez industry. A training session, hosted by Alliance Technologies in September 1990, was attended by over 200 persons who were instructed how to do the various calculations required to estimate industrial pollutant sources. Plans were also made for Alliance and SEDUE personnel to visit many Cd. Juarez industrial sites in March 1991 to assist local plant engineers in the completion of the questionnaire.

Unfortunately, the site visits planned for March 1991 were canceled by SEDUE for reasons which were not communicated to US counterparts. Emissions data that were collected from industry and submitted to SEDUE offices in Cd. Juarez were not shared with the EPA as originally anticipated. The exercise was moderately successful in bringing together government and industry partners and increasing emissions data return to SEDUE. However, it also illustrates the importance of having a clearly understood policy of cooperation with environmental officials in the Mexican government.

4.7 Short-term Winter Particulate Study -- Texas Air Control Board, Sandia National Laboratories, 1990

A winter-season study staged at a number of air sampling and meteorological sites spanning about one-month in December 1990 was funded by EPA-Region 6 with the TACB and Sandia National Laboratories taking lead roles in study design and data analysis. The primary focus of this study involved the collection of size-segregated particle samples followed by determination of the elemental and carbon species composition of the aerosol. These data were used in an initial assessment of the applicability of receptor modeling techniques for PM_{10} source apportionment. Additional measurements of local meteorology were carried out during periods of air stagnation. Data from a number of continuous monitors were also collected in order to characterize temporal features of the data during the winter season. A detailed discussion of this study along with analysis results is found in Section 5 of this report.

4.8 PM_{10} Modeling Plan Assessment and Recommendations -- Systems Application International, 1991

EPA-Region 6 commissioned a study by Systems Application International to review the various PM_{10} modeling approaches that might be used in state implementation plan development for the El Paso-Cd. Juarez airshed [Gray, 1991]. The overall objective of this study was to identify candidate receptor and/or dispersion models that could be successfully used in the El Paso-Cd. Juarez airshed to more fully understand the release and transport of PM_{10} in the local airshed.

The report presents a short summary of the multi-agency PM_{10} scoping study discussed at length in a later section of this report. Following the summary, a number of air quality models potentially useful in the process of state implementation plan development are reviewed and discussed. The authors break down the modeling approaches into the following three categories.

> **Dispersion Models** - Gaussian plume models, lagrangian trajectory models and eulerian grid models are all included in this category. All these models require emission inventories and detailed wind information.

Receptor Models - Included in this category are chemical mass balance models, factor analysis and multiple linear regression techniques. Receptor models, in contrast to dispersion models, do not require emission inventories, but instead rely on the characteristics of the collected data set at sampler locations to infer the type and strength of pollution sources contributing to what is measured at the collection site.

Wind Field Models - These models are used to produce gridded wind flow information for use by various dispersion models. These are further broken down into diagnostic and prognostic techniques.

The authors present a discussion of the strengths and weaknesses of the various dispersion models, both approved and unapproved by the EPA, for possible use in El Paso SIP development activities. Highlights of these discussions are summarized below:

RAM - Multiple Source Air Quality Algorithm, [EPA, 1986] -- gaussian plume model -- EPA approved for PM_{10} -- good source treatment -- no complex terrain -- problems with stagnation conditions

ISCST, ISCLT - Industrial Source Complex Short/Long Term, [EPA, 1986] -- gaussian plume -- EPA guideline model for PM_{10} SIP development -- good point source treatment -- problems with stagnation conditions -- poor treatment of area sources

PIC - Particle-in-Cell, [Marlia, 1990] -- 3-D lagrangian trajectory model -- not a EPA guideline model -- area sources treated as ground level point sources -- can determine contributions to overall PM_{10} from individual source categories -- can accept complex terrain wind information

WYNDvalley - Two layer Eulerian grid model, [Harrison, 1988] -- not an EPA approved model -- attempts to deal with dispersion under stagnation or near-stagnation conditions - requires trial and error approach for best results

GRID, [ODEQ, 1990] - Eulerian grid model -- not EPA guideline model - can model different sources distinctly - includes met processor for hourly 3-D winds

UAM - Urban Airshed Model, [EPA, 1990] -- Eulerian grid model - EPA approved for urban ozone modeling - modifications required to run multiple particle sizes in the PM_{10} category -- takes complex terrain into account -- computationally intensive and not well suited for annual modeling however alternative strategies have been suggested -- takes gridded wind field data from Diagnostic Wind Field Model

RTM/UAM-V - Regional Transport Model, [Stewart, 1986] -- Eulerian grid model -- not an EPA guideline model -- similar to UAM in many respects -- forms the basis of recent UAM-V release -- takes complex terrain into account -- includes secondary sulfate aerosol formation mechanisms

A similar summary of a much shorter list of receptor models discussed by the authors is given below:

CMB - Chemical Mass Balance, [EPA, 1986] -- primary receptor modeling technique -- requires source profiles which are statistically fit to profiles measured at sampling sites--

- assumes no aerosol transformation from source to receptor -- cannot distinguish between sources with similar chemical composition in their emissions

SAFER - Source Apportionment by Factors with Explicit Restriction, [Henry, 1988] -- uses factor analysis to extract information on sources from data -- can predict source compositions and strength -- source libraries not required

Finally, a summary of the various approaches to the development of wind field data required by many of the dispersion models presented by the authors is given below:

WEST - Winds Extrapolated from Stability and Terrain, [ODEQ, 1990] -- a diagnostic wind field model -- produces 3-D (2 vertical layer) wind field each hour -- extrapolates actual measurements from the grid -- simple modeling approach

DWM - Diagnostic Wind Model, [Douglas, 1988] -- diagnostic model used for input to UAM -- interpolates surface and upper air measurements -- calculates vertical velocity -- concerns about accuracy in vertical velocity calculations

CSUMM - Colorado State University Mesoscale Model, [McNider, 1981] -- a prognostic hydrostatic primitive equation model -- optimized for shallow slope terrain -- exhibits questionable nocturnal flow features along highly sloped terrain

HOTMAC - High Order Turbulence Model for Atmospheric Circulations, [Yamada, 1989] -- a hydrostatic primitive equation model -- predicts wind, temperature, humidity and atmospheric turbulence -- can utilize nested grids (coarse for boundary conditions and fine for the area of interest)

PSUMM4 - Pennsylvania State University Mesoscale Model, [Anthes, 1978] -- hydrostatic terrain-following model -- nested grids available -- optimized for regional scales of 100 to 1,000 km -- costly to apply and run on a smaller grid size

RAMS - Regional Atmospheric Modeling System -- a non-hydrostatic prognostic model -- evolved from CSUMM -- high horizontal resolution of small-scale processes possible -- grid nesting available -- output in spherical coordinates that require post-processing into the more conventional UTM coordinate system.

The authors draw several conclusions concerning the application and use of dispersion and receptor models to the problem at hand in the El Paso-Cd. Juarez locale. First, a recommendation is made to apply a dispersion model such as UAM to PM_{10} dispersion in the area. The authors note that the quality of the model output is only as good as the source information used for input. The lack of credible emissions data from Mexico is also recognized as a potential problem in this approach. The authors note that minor modifications would be necessary to apply the UAM model to PM_{10}. The model should be run in a so-called "inert" mode and similar emissions from Mexico and US should be "tagged" separately; however, the authors do not give details here. Secondly, the authors recommend the use of the CMB receptor model to complement the dispersion model efforts. Results from the CMB model may be useful in understanding sources in the region for which emission inventory data are either missing or incomplete.

4.9 PM_{10} SIP Development -- Texas Natural Resource and Conservation Commission, 1991

The TNRCC in accordance with recent enactments of the US Clean Air Act have submitted a PM_{10} State Implementation Plan (SIP) that puts forth a detailed agency analysis of measured PM_{10} levels, inventoried PM_{10} sources and dispersion model calculations intended to reveal PM_{10} pollution trends in the region along with the modeled effects of various PM_{10} control measures [TNRCC, 1991]. An internal study of measured PM_{10} levels in El Paso during the years 1986 - 1990 revealed that exceedences of the PM_{10} standard occurred most frequently during winter months and that most occurred during winter meteorological stagnation events. The El Paso PM_{10} SIP also draws upon the results from special studies conducted in the area under the Annex V program. Reference is made to the Winter 1990 Intensive PM_{10} study discussed in greater detail in Section 5 of this report. The SIP report also describes the TNRCC's effort to develop comprehensive emission inventories for El Paso County for the years 1990 and 1994. December 31,1994 is the CAA-mandated PM_{10} attainment date for El Paso County.

The TNRCC analysis was designed to predict local impact of US sources only, so no attempt was made to account for emissions from the Mexican side of the border. By employing Section 179(b) of the CAA and showing that El Paso County would attain the PM_{10} standard "but for" emissions from Mexico, TNRCC would then avoid a reclassification of El Paso's non-attainment status to "serious' if El Paso failed to attain required air quality by December 31, 1994.

The US emission inventories were combined with meteorological data from the El Paso airport that spanned the years 1985 through 1989. An EPA regulatory model known as the Gaussian-Plume Multiple Source Air Quality Algorithm (RAM) was used for predicting PM_{10} impacts from 1990 and 1994 emission inventories over a large receptor grid. The model assumes flat terrain which was judged to be acceptable by TNRCC staff since major sources were understood to be at ground level and located in the flat, valley bottom of the region. In general, model runs for one-year intervals revealed annual average PM_{10} concentrations in the vicinity of 40 $\mu g/m^3$ at so-called "hot spot" receptor locations at which the highest predicted PM_{10} levels were encountered. Approximately 70% of this average annual PM_{10} value was attributed to sources in the inventory with the remainder attributable to regional background aerosol. Similar model runs for 24-hour intervals revealed maximum concentrations ranging from about 90 to 130 $\mu g/m^3$.

The modeling analyses reveal no exceedences of US air quality standards by 1994 as a result of US sources alone. Consequently, the TNRCC concluded that PM_{10} transport from Juarez sources account for 24-hour PM_{10} levels above the US standard that are occasionally measured at the various PM_{10} monitoring sites throughout El Paso.

4.10 Cd. Juarez Industrial Emissions Study -- EPA-SEDESOL, 1992-93

During September 1992, a cooperative study was conducted by EPA Region 6 along with SEDESOL, EPA's Mexican counterpart, of air emissions from typical industrial source-types in Cd. Juarez. This project was initiated following a specific request from SEDESOL at the June 1992 Binational Air Workgroup meeting. EPA Region 6 coordinated the involvement of personnel from the EPA Office of Air Quality Planning and Standards, Texas Air Control Board, California Air Resources Board, California South Coast Air Quality Management District and the City of El Paso in a series of one-week field visits with SEDESOL staff from Cd. Juarez, Mexico City and Tijuana. Five facility reports were jointly written by US and Mexican participants that estimated air emissions, recommended easily implemented controls and a Reasonably Available Control Technology strategy for each industry visited. The data collected during this project provided the first in-depth inventory of major sources in Cd. Juarez using US government personnel and gave significant insights into similarities and differences between US and Mexican industrial plants. The project also provided opportunities for technology transfer between US and Mexican counterparts.

The facility reports and raw data produced during this project are considered proprietary information, as specified in Article XVI of the 1983 La Paz Environmental agreement between Mexico and the US. Public release of the data or reports by the US is subject to the approval of the Government of Mexico [Yarbrough, 1994].

In November 1992 and November 1993, TNRCC and EPA Region-6 personnel presented emissions inventory training to over 100 SEDESOL engineers. The primary objective of the training exercise was to transfer emissions gathering technology to SEDESOL staff so that they would be more comfortable in planning and conducting future Juarez inventories. Although the training sessions were judged to be successful in giving SEDESOL engineers the technical skills needed to carry out emissions estimation calculations, no follow-on special Juarez industrial inventory was conducted by SEDESOL as anticipated.

4.11 Vehicle Emissions Remote Sensing Study -- University of Denver, 1993

In March of 1993 a consortium that included EPA Region 6 commissioned a research group at the University of Denver to conduct a number of on-road measurements of vehicle emissions in both El Paso and Cd. Juarez [Stedman, 1993A and Stedman, 1993B]. This university research group has developed an infrared remote sensing unit that is capable of measuring CO_2, CO and hydrocarbon tailpipe emissions from a single on-road vehicle in less than one second. An infrared beam is aimed from a source across the road at tailpipe height, passed through a series of narrow band filters and projected onto detectors that yield a measure of selected gases in the exhaust plume. The system is capable of continuous sampling in a traffic stream such that the emissions from a large number of cars can be recorded and compiled into a fleet profile for a particular area. The license plate of the automobile is also recorded by a video system. With appropriate labor resources, these video data provide a means of determining vehicle year, model type and owner for additional definition of the local vehicular fleet composition.

A prototype model of a remote sensing unit designed to concurrently measure NO emissions by measuring its absorbance in the UV portion of the spectrum was also tested on selected days during the study interval. A limited amount of data from this unit are reported as well.

Testing began on March 15 and was completed on March 25. The remote sensing apparatus was sequentially set up at four locations in El Paso and seven locations in Cd. Juarez. Locations in El Paso were the Yarbrough on-ramp to eastbound I-10, the westbound on-ramp to I-10 at Sunland Plaza, the Altura on-ramp to southbound US 54 near Fort Bliss and the on-ramp from both southbound and northbound US 54 onto eastbound I-10. Locations in Cd. Juarez included a right turn lane from northbound Lopez Mateos onto eastbound De La Razza, a left turn lane at the San Lorenzo intersection, the northbound ramp to the Bridge of the Americas (the only cloverleaf junction in Cd. Juarez), a left turn lane from Thomas Fernandez onto Ave de la Industria in one of the industrial sectors of the city, a single lane near the Lucerna Hotel and a single entrance lane into the parking lot of the Juarez municipal building.

A summary of the measurement results showing the mean and median values of CO and hydrocarbons (HC) as percent volume of total exhaust along with the number of cars monitored at each site is given in Table 3. Figures 11 and 12 provide additional detail of the tailpipe emission distributions for CO and HC by apportioning the total number of cars sampled into deciles with an emission level associated with each decile. A number of conclusions are summarized from the report as follows:

> The average CO level compiled from about 16,000 vehicles at all sites in El Paso was 1.2%. Carbon monoxide levels in Juarez were nearly three-fold higher with a mean of about 3.0% as compiled from about 7,500 vehicles. The authors note that Juarez emission levels are clearly higher than typical US urban levels however, they are lower than levels measured in Mexico City.
>
> Hydrocarbon (HC) emission levels show similar trends as noted for CO, with the El Paso mean HC at 0.07% and the Cd. Juarez mean at 0.17%.
>
> Site-to-site differences for both CO and HC were minimal for the Cd. Juarez data set. Differences in CO and HC emissions were noted between the more affluent section of El Paso near Sunland Plaza and other parts of the city. The lower levels encountered near Sunland Plaza are attributed to a higher fraction of newer cars equipped with enhanced emission control equipment.
>
> The decile plots (Figures 11 and 12) for both CO and HC reveal differences in the emissions from the vehicle fleets of the two cities. The highest CO emitting group in El Paso has a similar average %CO level as the three highest deciles in Cd. Juarez. Thus, there are more "broken" vehicles in Cd. Juarez, but the emission level of a high emitting vehicle is about the same in both cities.
>
> The lowest emitting vehicles in El Paso emit at a much lower (nearly three-fold) level than the lowest emitting category in Cd. Juarez. The authors attribute these differences to the presence of many more US vehicles possessing the newest "closed-loop" emission control technology.

The authors point out a two-fold utility in making such remote sensing measurements. First, individual high emitting vehicles can be detected and repaired or otherwise dealt with under appropriate local agency programs. Second, a city-specific emission rate for CO, NO and hydrocarbons can be determined to reasonable accuracy since formulae are available for converting measured average %CO values to grams of CO emitted per gallon of fuel consumed. Fuel consumption figures can then be combined with the average emission rates to estimate total emission levels of the El Paso and Cd. Juarez vehicular fleets for pollutant species such as CO,NO or hydrocarbons that are of interest in SIP development for PM_{10}, CO or ozone control.

Table 3
Summary CO and HC Tailpipe Emissions
from the University of Denver Remote Sensing Study

Sampling Site	Date	Vehicle Count	Mean CO (%, v/v)	Median CO (%, v/v)	Mean HC (%, v/v)	Median HC (%, v/v)
Yarbrough	3/15/93	5273	1.55	0.63	0.08	0.06
Yarbrough	3/16/93	5811	1.42	0.47	0.07	0.05
Sunland	3/17/93	4035	0.84	0.26	0.08	0.05
Altura	3/18/93	2220	1.59	0.53	0.07	0.05
Eastbound I-10	3/19/93	6534	1.25	0.37	0.07	0.04
El Paso Overall		**15986**	**1.22**	**0.37**	**0.07**	**0.04**
Lopez Mateos	3/22/93	391	3.48	2.73	0.19	0.11
San Lorenzo	3/22/93	1802	2.90	2.20	0.18	0.10
Bridge Ramp	3/23/93	601	2.81	1.72	0.15	0.08
Cloverleaf	3/23/93	673	2.81	1.96	0.13	0.08
Industrial	3/24/93	1303	2.72	1.87	0.17	0.08
Hotel	3/24/93	1239	3.21	2.35	--	--
Municipal Bldg	3/25/93	1631	3.04	2.41	0.18	0.09
Juarez Overall		**7640**	**2.96**	**2.18**	**0.17**	**0.09**

from [Stedman, 1993A]

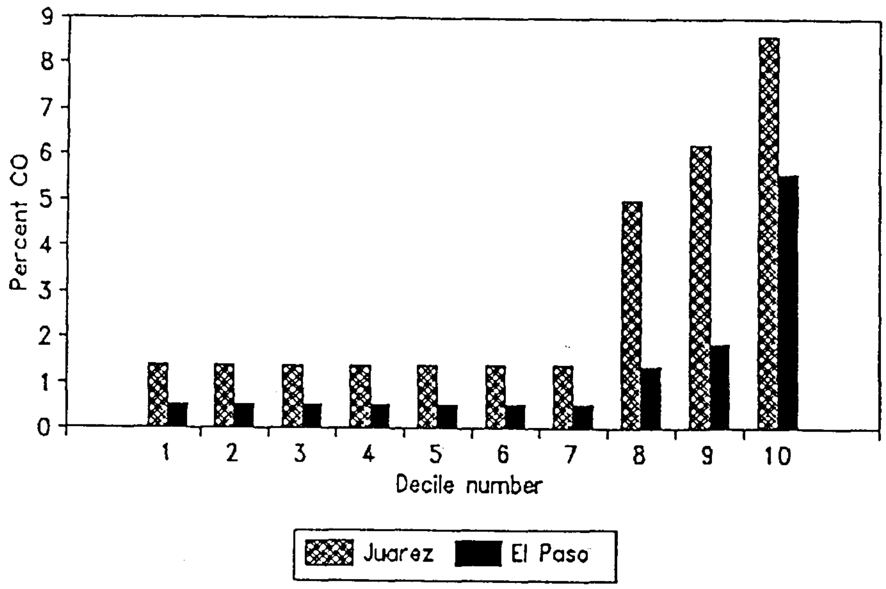


Figure 11 Decile emissions in %CO for vehicles measured in El Paso and Cd. Juarez [from Stedman, 1993B].

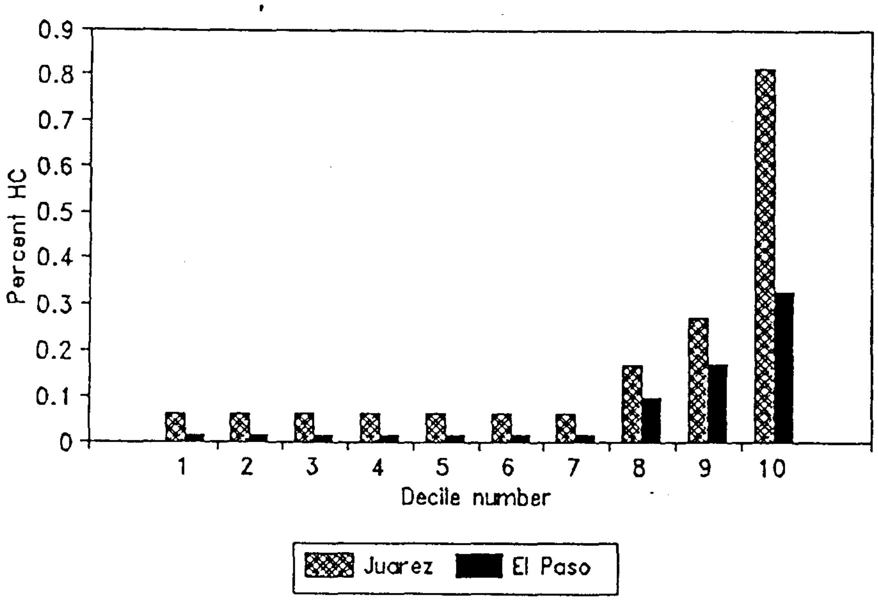


Figure 12 Decile emissions for HC in %propane for vehicles measured in El Paso and Cd. Juarez [from Stedman, 1993B].

4.12 MOBILE5 Revisions -- Energy and Environmental Analysis Inc., 1993

In order to obtain better vehicular emission estimates for Cd. Juarez, the Emission Control Strategies Branch of the EPA commissioned Energy and Environmental Analysis Inc. to revise the EPA MOBILE5 Vehicular Emissions Code so that it could be applied to the Cd. Juarez fleet [EEA, 1993]. The current MOBILE5a model has hard-coded, non-changeable inputs for vehicle control technologies as they were implemented in vehicles sold in the US (with the exception of the State of California) over the past few decades. As such, the code is applicable to all US states with the exception of California since different control technologies have been implemented there. By the same argument, the code is also not suitable for use in Cd. Juarez. Modifications were made to the code to allow greater input flexibility and thus applicability to Cd. Juarez. The modified code is designated MOBILE5c and is suitable for use in any US or foreign location, provided that the appropriate input data for the vehicular fleet of interest are available.

4.13 Cd. Juarez Vehicle Fleet Characterization -- Texas Transportation Institute, 1993

In the interest of better definition of Cd. Juarez vehicular pollutant sources, the TNRCC commissioned the Texas Transportation Institute to conduct a multi-tasked study in the city during the summer of 1993 [TTI, 1994]. A total of six specific tasks related to the refinement of the Cd. Juarez vehicle fleet characteristics, designed to yield better MOBILE5 input, are described below. A summary of the more important results is also given for each task.

Vehicle Speed Study - Various surveys were carried out to estimate travel time and average vehicle speeds throughout the city. Average speeds ranged from as low as 14.5 mph during midday periods on undivided arterials in the central business district to a high of 33.1 mph at midday on rural divided arterials. Table 4 summarizes overall average speeds by roadway class and time of day.

Table 4
Average Speed (MPH) by Roadway Class and Time of Day

Roadway Type	AM	Off-peak	PM	Daily
Divided Arterial	27.0	25.4	24.6	24.8
Undivided Arterial	20.2	18.9	18.6	18.6
Other Arterial	22.8	21.6	22.2	21.8
Collector	17.0	17.0	16.4	16.4

from [TTI, 1994]

Vehicle Miles Traveled (VMT) Mix Study - Vehicle count surveys were carried out to specify the fraction of total vehicle miles traveled in the urban area by each of the eight vehicle categories used in the MOBILE5 model. The overall VMT mix by vehicle classification is given in Table 5. An estimate of traffic activity showing the percent of total 24-hour activity by hour of the day is given in Figure 13.

Table 5
Overall Cd. Juarez VMT Mix

Vehicle Type	Percent of Total
Light Duty Gas Vehic.	61.1
Light Duty Gas Truck1	24.2
Light Duty Gas Truck2	6.6
Heavy Duty Gas Vehic.	5.6
Light Duty Diesel Vehic.	0.0
Light Duty Diesel Truck	0.0
Heavy Duty Diesel Vehic.	1.9
Motorcycles	0.6

from [TTI, 1994]

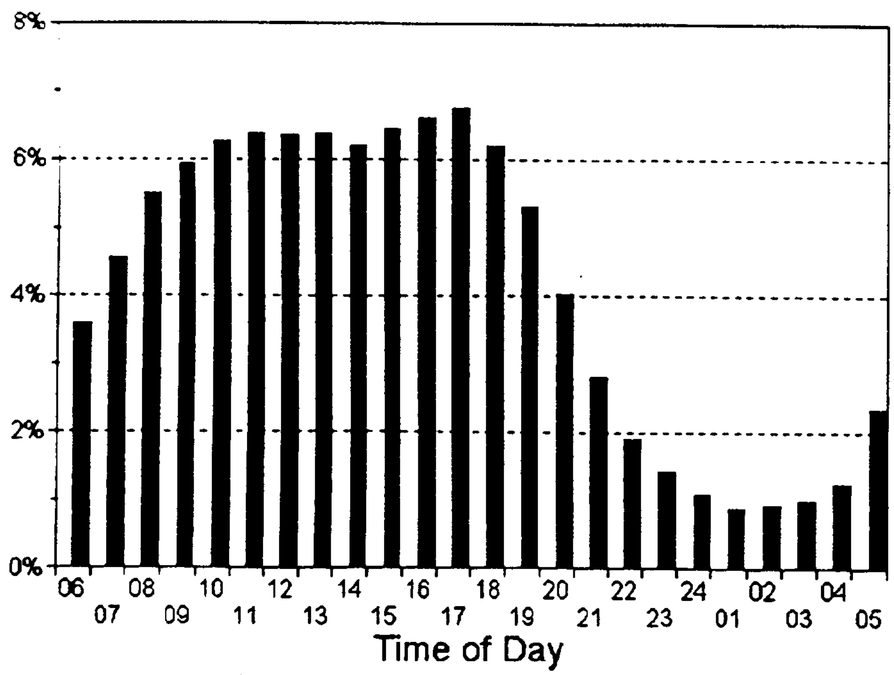


Figure 12 Estimate of daily Cd. Juarez traffic activity by hour of the day [from TTI, 1993].

Operating Mode Study - Home interviews on vehicle usage, normally used to determine vehicle mode usage, were not carried out in this study. Instead, estimates of the fraction of vehicles operating in the area under various engine temperature conditions (e.g. percent cold vehicle starts) were derived from data collected in other US cities. These were combined with average trip duration estimates for Cd. Juarez to estimate overall engine mode usage. Not surprisingly, overall results pertaining to mode usage did not differ significantly from other US cities.

Vehicle Registration - An extensive vehicle sampling survey was conducted to determine the percentage of total vehicles in the city that were Mexico-registered, US-registered or non-registered. A compilation of all survey results revealed that about 62% of all vehicles had Mexico registry, 15% US registry with the remaining 23% having no registry. Survey results are summarized by age of vehicle in Table 6.

International Bridge Study - Vehicle sampling surveys were conducted at the Paso del Norte Bridge (Sante Fe Street), Bridge of the Americas (Free Bridge) and Zaragosa Bridge to determine typical vehicle wait times for US-bound vehicles throughout the day. The authors observe that the number of vehicles passing over the various bridges in a 24-hour period ranged from 10,000 to more than 31,000 in July 1993 when the survey was conducted. The highest traffic volume was noted on the Bridge of the Americas. Typical wait times for crossing from Mexico to the US at this bridge were a function of the day of the week and the time of day and ranged from less than 10 minutes to in excess of 30 minutes with the longest times occurring on weekdays between 1200 and 1500 hours. About half of the vehicles passing though were of Mexican registry with the remainder of US registry.

Table 6
Registration Information by Vehicle Age

Age of Vehicle, (Total No.)	Percent of Total Vehicles in Category		
	Mexico Registered	US Registered	Non-Registered
Pre-1979 (99,961)	61	9	30
1979-1985 (156,193)	59	16	24
1986-1993 (53,311)	54	33	13
Overall (309,195)	59	17	24

from [TTI, 1994]

VMT Estimation - A number of traffic count surveys were carried out and coupled with estimates of average vehicle trip lengths to produce an estimate of total VMT in the city. The results of this survey are summarized and compared with similar El Paso data in Table 7. The results indicate that Cd. Juarez has about 34% of the EL Paso VMT, while it has about 16% fewer cars than El Paso. Thus, average car usage is less in Cd. Juarez than in El Paso.

Table 7
Cd. Juarez and El Paso Vehicle Use Comparisons

Parameter	Cd. Juarez 1993	El Paso 1990	JAZ/ELP Ratio
Total VMT	3,394,000	9,900,000	0.34
Total Vehicles	309,000	364,000	0.85
Total Population	1,200,000 (est.)	591,600	2.02
Total VMT per Capita	2.8	16.7	0.17
Vehicles per Capita	0.26	0.62	0.42

from [TTI, 1994]

4.14 Cd. Juarez Brickmaker Study -- El Paso Natural Gas Co./FEMAP, 1993

The El Paso Natural Gas Company, in collaboration with the Mexican Federation of Private Health and Community Development 'Associations (FEMAP), sponsored a study of the brickmaking industry in Cd. Juarez [Johnson, 1994]. The primary focus of this study was to strengthen the ability of the traditional Mexican brickmaker to earn a living from his trade in the face of mounting pressure from Mexican pollution control agencies such as SEDESOL to curtail emissions from primitive brick kilns. The authors estimate that approximately 400 brickmaking operations are located in Cd. Juarez providing employment for about 2,500 citizens. Traditionally, the brickmaker scavenges for fuel to fire the kiln. Fuels include such materials as sawdust (either clean or contaminated with plastics or glues), used motor oil and rubber tires. Use of these fuels results in appreciable pollution emissions with the brickmaking industry ranked the fourth largest pollution source in Cd. Juarez by some. The authors report accomplishments in the following areas as a result of this on-going project:

Process and Economics Improvement - The newly-formed coalition has set guidelines for the use of clean burning fuels, standardized brick dimensions, and brick price stabilization.

Testing Burner Efficiency - Studies were conducted to evaluate the efficiency of various propane burners used in kiln firing operations. Emissions rates of pollutant gases such as SO_2, CO and NO_x were measured to optimize burner design and fuel usage.

Pollutant Emissions from Various Fuel Types - Emission testing was carried out on the various fuels traditionally used to fire the brick kilns. The authors report measurable levels of such pollutants as CO, NO, NO_2 and SO_2 for such fuels as clean sawdust, used motor oil, old propane burner, contaminated sawdust and new propane burner. The contaminated sawdust category showed the highest emission rates for all pollutants. Particularly high levels of CO (2,700 - 29,000 ppm) and SO_2 (20 - 225 ppm) were measured for contaminated sawdust. The authors do not report pollutant emissions in terms of emission factors (mass of pollutant per mass of fuel consumed) however. The emission measurements did not include an analysis of the elemental composition of the particulate emissions. The authors noted that bulk motor oil was analyzed for elemental content and observed that the oil contained significant quantities of lead, arsenic, chromium, cadmium, copper, selenium and mercury.

Improved Kiln Design - Various innovative kiln designs were tested at a local training center set up in Cd. Juarez as a part of the project. Kiln designs were evaluated with regard to heating uniformity, brick processing time and waste heat recovery. The authors note that in many cases, brick production and quality were improved by implementing these changes.

4.15 Pollutant Emissions from Residential Heaters -- University of Utah, 1993

A consortium of southwestern US universities, known as the Southwest Center for Environmental Research and Policy (SCERP) has also secured EPA-Headquarters funding to study air pollution issues along the US-Mexico border. In recent years, the University of Utah, one of the member institutions, has conducted studies to assess the air emissions from domestic heating systems commonly used in Cd. Juarez. The overall objective of the project was to develop low-cost technology to reduce toxic hydrocarbon emissions from domestic heating and other incineration systems fired with various fuels [Lighty, 1993]. Studies were conducted jointly with the Technical Institute of Juarez to measure emissions from a typical residential heater using three fuel types, namely, Mexican-made pallets, US-made pallets and scrap particle board covered with plastic laminate. Emission measurements included on-line determinations of CO, THC, CO_2, O_2 and NO along with speciation of volatile hydrocarbons using a fast-response GC-MS. Particulate matter samples were also collected using EPA Method 5H. A summary of gas emission factors for the various fuels tested is given in Table 8.

Table 8
Gas and Total Hydrocarbon Emissions Factors for Selected Waste Wood Fuels

Fuel Type	CO, g/kg	THC, g/kg	NO, g/kg
US Pallet	60 ± 3	4.7 ± 0.3	0.8 ± 0.1
Mexico Pallet	37 ± 9	3.5 ± 1.3	0.7 ±0.1
Particle Board	95 ± 4	3.1 ± 0.6	3.7 ± 0.1
AP-42 Residential Wood [EPA, 1985]	61.1	95.1	0.9

from [Lighty, 1993]

The morphology of collected smoke particles was examined using scanning electron microscopy. The investigators report the presence of chain agglomerate structures indicative of soot particles. Further analysis was done in both the gas phase and the collected particulate material using an ion trap GC-MS system to speciate volatile and semi-volatile hydrocarbons. Four major compounds identified in the samples were furan, benzene, toluene and furaldehyde. The presence of polynuclear aromatic compounds was also reported. The investigators note that analysis for chlorinated hydrocarbon species was not carried out in this set of experiments, however they observe that the laminated particle board contained significant amounts of chlorine which would likely produce chlorinated organic species during combustion.

4.16 Upper Air Wind and Temperature Data Collection -- University of Texas at El Paso, 1993

The Electrical Engineering Department at UTEP was funded as one of the member universities of the Southwest Center for Environmental Research and Policy to install and operate a three-axis 915 MHz wind profiler and acoustic sounding system for the collection of winds and temperature aloft data at the UTEP campus. The system was installed and operational by October 1993. Temperature data are available from about 100 to 600 meters above ground level. Wind data are available from 100 meters to 2,000 meters above ground. Data are processed and archived as hourly, daily, monthly and seasonal averages and variances. The system was used for a winds aloft data cross comparison in a recent lidar technology demonstration project briefly discussed in the final section of this report.

4.17 Oxygenated Fuel Use in El Paso-Cd. Juarez -- SEDESOL and others, 1993

El Paso is classified as a moderate CO non-attainment area. While the US Clean Air Act Amendments of 1990 do not require El Paso to institute a winter oxygenated fuels program, the City of El Paso nevertheless chose to implement one, beginning in December 1991. The initial oxygenate blend was 2.4%, and was raised in winter 1992-93 to 2.7%. The city made the decision to initiate such a program as a result of the apparent CO reductions experienced by other Southwestern US cities, such as Albuquerque, with oxy-fuels programs. At this point in time no systematic studies have been carried out to examine the effects of oxygenated fuels on winter season CO levels in El Paso. However, average CO levels at least qualitatively reveal a decline over the past several years.

The US EPA and the Government of Mexico have discussed the possible introduction of oxygenated fuels in Mexico as well. A pilot program was carried out from January 1, 1993 to February 15, 1993 during which Mexican officials allowed oxygenates to be included in unleaded gasoline supplied by US refineries to Cd. Juarez markets. The effects of this introductory program have not been systematically evaluated at this point in time.

4.18 Other Activities -- Paso del Norte Air Quality Task Force, 1993

A coalition of government, industry and non-government organization representatives came together in 1993 to form the Paso del Norte Air Quality Task Force. The group, with representatives from EPA, SEDESOL, Cities of El Paso and Cd. Juarez, the States of Texas, New Mexico, Chihuahua as well as non-government organizations and the public originally came together as an advisory committee to the TACB, TNRCC's predecessor. The organization was elevated to a task force in September 1993 when the TACB was combined with other Texas state agencies to form the TNRCC.

At present, the group, working in concert with the Environmental Defense Fund, is focusing on short-term air pollution emission reduction strategies that can be easily implemented. Current efforts at air emissions reduction include: developing strategies for the reduction of VOC emissions from small auto body shops; defining actions to reduce excessive idling vehicle queues at the international bridges; and, assisting in the training of mechanics who are charged with the repair of vehicles that fail the inspection and maintenance program in Cd. Juarez. The task force has also contributed to the Cd. Juarez Brickmakers study summarized earlier in this report.

A longer-term goal of the Task Force is the development of an International Air Quality Management District (IAQMD). The formation of this international air shed has been proposed by the Task Force as an annex to the 1983 US-Mexico Border Environmental Agreement. The IAQMD would consist of a governing board of directors that would encourage common approaches to enforcement, monitoring, regulations and public outreach among the various air pollution control agencies in the airshed. Economic incentive programs would also be proposed to aid in air pollution reduction in the airshed. For example, one such economic incentive might involve the designation of international air pollution credits trading, much like those implemented as a part of the recent US Clean Air Act legislation. This scheme would enable a US industry interested in plant expansion on the US side of the border to finance air pollution controls on the Mexican side of the border, and in the process, "bank" air pollution credits for use as an offset for pollution increase on the US side that may arise as a result of plant expansion. Provided that the Mexican plant pollution reduction is greater than the US pollution added (by some ratio to be agreed upon), the credit trading system offers some attractive alternatives for control of Cd. Juarez industrial pollution sources through financing by US investments while allowing US industry to expand in an otherwise highly restrictive non-attainment environment in El Paso.

The EPA and the US Department of State are currently reviewing the proposal for the formation of a formal IAQMD, forwarded by the State of Texas on behalf of the Task Force in September 1993.

4.19 Comparison of Vehicle Emissions Inspection and Maintenance Programs in Cd. Juarez and El Paso -- Paso del Norte Task Force, 1994

A comparison of the El Paso and Cd. Juarez vehicle emissions inspection and maintenance program was carried out in early 1994 by a member of the Paso del Norte Air Quality Task Force [Rincon, 1994]. In his introductory comments, the author notes the significant population growth of the Pas del Norte trade area, as shown in Figure 14. The author's estimates of total population in the region by the year 2000 is on the order of 2.6 million people. Motor vehicle registrations show similar dramatic increases over the past 20 years, particularly in Cd. Juarez.

Other observations made by the author with respect to the I/M programs in both El Paso and Cd. Juarez are summarized in the following paragraphs.

> Tailpipe emission standards for CO and hydrocarbons in El Paso and Cd. Juarez are summarized in Figure 15. In general, the requirements are more stringent in El Paso for both CO and hydrocarbons. For 1981 and newer vehicles, El Paso's standards are markedly more stringent.
>
> In 1993, about 160,000 vehicles were inspected in Cd. Juarez, a number equivalent to about 50% of the total number of registered vehicles in Cd. Juarez. The Municipal Ecological Committee reports a failure rate of 9.5% of all vehicles tested.

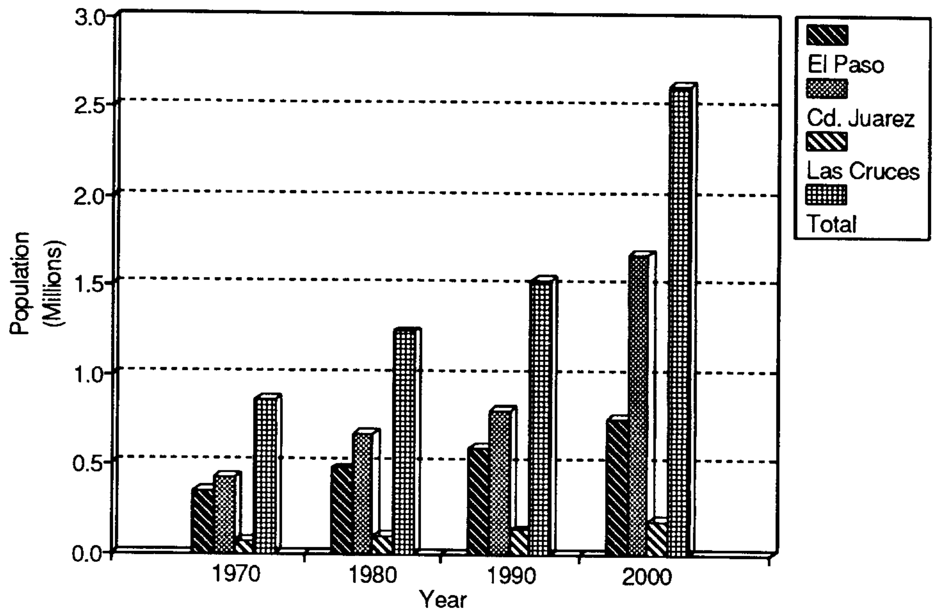


Figure 14 Population trends in El Paso and Cd. Juarez [from Rincon, 1994].

As of April 15, 1994, about 96,000 light duty trucks and passenger vehicles were inspected in Cd. Juarez. A failure rate of about 48% is reported, which stands in marked contrast to 1993 inspection data.

Inspection data for El Paso as tabulated by the TNRCC for 1993 is shown graphically in Figure 16. The inspection failure rate is shown by vehicle year. The overall 1993 failure rate for all vehicles was about 15.3%.

The author notes that current Mexican import laws tax imported US vehicles less than 5 years old at 100% of their import value. These restrictions result in an older vehicle fleet with greater tailpipe emissions in Cd. Juarez as compared to El Paso.

Many of the inspection and maintenance centers in Cd. Juarez do not have fully trained mechanics doing I/M testing and repairs. The Comite Municipal de Ecologica has implemented introductory technical seminars for I/M inspectors to assess their level of knowledge and provide instruction on analyzer operation (See Section 4.20).

Educational programs are needed in Cd. Juarez in order to raise awareness of the population to the requirements and benefits of an I/M program.

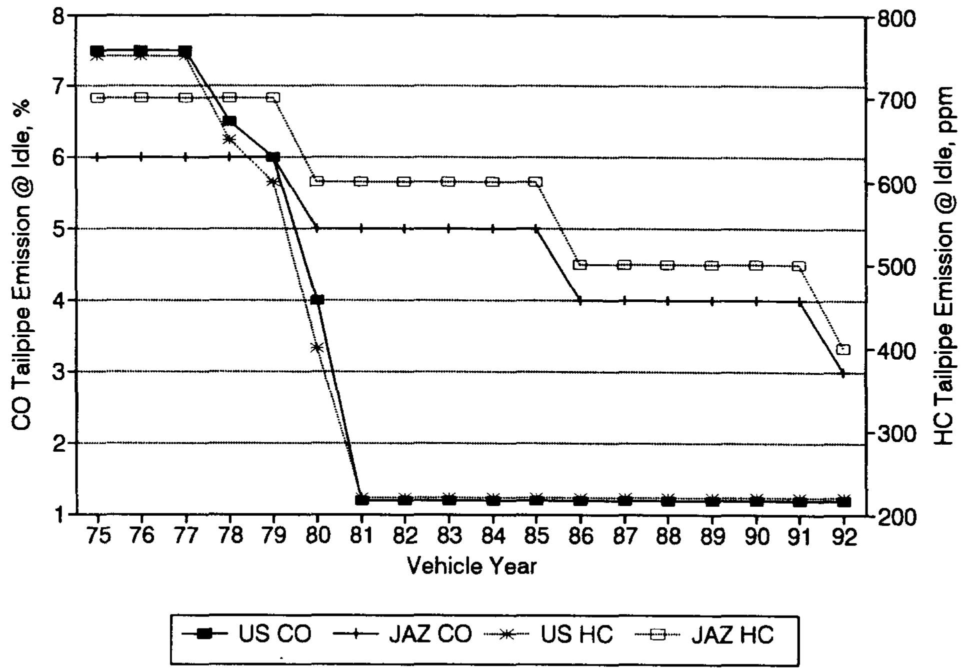


Figure 15 Vehicle CO and hydrocarbon emission standards established in El Paso and Cd. Juarez I/M programs [from Rincon, 1994].

The author also lists a number of recommendations for improvement of the Cd. Juarez I/M as summarized below.

Test all vehicles in the Cd. Juarez fleet under an expanded Cd. Juarez I/M program.

Develop an inspector/mechanic "hot line" for prompt resolution of technical questions.

Implement data management techniques to track I/M program performance.

Develop educational programs that are targeted to the general populace in order to raise their collective environmental consciousness.

Prioritize both traffic flow control measures and road pavement projects as a means of achieving pollution reduction associated with vehicle use in Cd. Juarez.

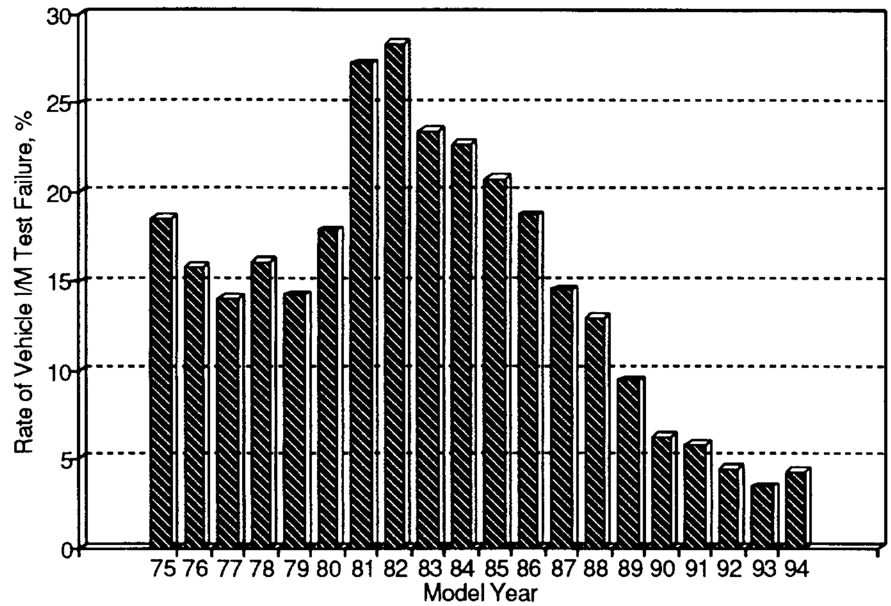


Figure 16 Vehicle failure rate by vehicle year encountered during 1993 in the El Paso I/M program [data from Rincon, 1994].

4.20 Technology Transfer Session with I/M Technicians -- Colorado State University, 1994

Colorado State University, under contract to the EPA Office of Mobile Sources, performed two hands-on technology transfer sessions with Juarez I/M technicians in 1994 [Friedt, 1994]. The sessions were designed to better equip Cd. Juarez commercial mechanics to diagnose and repair typical vehicle emissions control system problems. The program was specifically developed to aid Juarez Comite Municipal de Ecologia in enhancing the positive impacts of the city's I/M program.

The project was initiated with a questionnaire administered to 14 automotive technology instructors in Cd. Juarez. The questionnaire was designed to assess the training needs of the Cd. Juarez automotive technicians and to assist in the development of the training course content. Survey respondents indicated a lack of training aids such as exhaust gas analyzers for instruction sessions on engine diagnosis and tune-up. Survey respondents also ranked academic needs for a course on mechanics training in emissions system repair as follows: (1) more effective teaching techniques; (2) emissions control systems training; (3) chemistry of pollutant formation; (4) fuel injection systems; and (5) electronic ignition systems.

The project team put drew a number of conclusions and recommendations from the survey results as briefly summarized below.

In general, the technician group in Cd. Juarez requires additional training in the areas of teaching methodology, causes of excessive vehicle emissions, emissions control system function and diagnosis/repair techniques.

The learning styles and reading skills of potential course participants vary widely and must be taken into account when designing course material for this technician population.

The instructional course should be a two-phase program with an approximate 6-month interval between phase one and two. This interval would allow an assessment of the degree of success reached with the introductory phase of the course, allowing further adaptation of the second phase of the course to student needs.

A communication network should be established between Mexican and US border community colleges with instructional capabilities in these areas to provide continued up-to-date training approaches and skills for automotive repair instructors and technicians.

5.0 Short-term Winter Season PM_{10} Study

5.1 Study Purpose and Scope

A winter-season study staged at a number of air sampling and meteorological sites spanning about one-month in December 1990 was funded by EPA-Region 6 with the TACB and Sandia National Laboratories taking lead roles in study design and data analysis. The primary focus of this study involved the collection of size-segregated particle samples followed by determination of the elemental and carbon species content of the aerosol. These data were used in an initial assessment of the applicability of receptor modeling techniques for PM_{10} source apportionment. Additional measurements of local meteorology were carried out during periods of air stagnation.

5.2 Measurement Techniques

Multiple samplers were deployed in this study in an effort to more completely characterize the pollutant composition and spatial distribution during winter stagnation events. Funding limitations prevented complete pollutant characterization during the entire study interval, however the aggregate of various measurements, although not continuous, did allow a reasonable characterization of winter season air quality. Table 9 lists the measured parameters along with instruments and lab analysis, where applicable.

Table 9
Air Pollution Parameters Measured
in the 1990 Winter Season Study

Measured Parameter	Instrument	Lab Analysis
PM_{10} Concentration (24-hr avg)	Hi-vol Sampler	Gravimetric analysis
Aerosol Concentration (12-hr avg) Fine, Coarse & PM_{10}	Dichotomous Sampler w/ Teflon Filter	Gravimetric analysis
Elemental Concentrations (12-hr avg) Fine, Coarse & PM_{10}	Dichotomous Sampler w/ Teflon Filter	X-ray fluorescence
Elemental and Organic Carbon Conc. (12-hr avg) Fine, Coarse and PM_{10}	Dichotomous Sampler w/ Quartz Filter	2-stage combustion analysis
PM_{10} Concentration (1-hr avg)	Beta-gauge sampler	None
Aerosol Light Scattering Coefficient	Nephelometer	None
Inorganic Gases and Aerosol	Annular Denuder	Ion chromatography
Gas Criteria Pollutants (CO, NO_x, O_3, SO_2)	Continuous Monitors	None
Semi-volatile organics	Hi-vol sampler with PUF Cartridge	Gas Chromatography/Mass Spectroscopy
Wind Speed & Direction	Anemometer	None
Temperature	Thermocouple	None
Winds aloft, atmospheric mixing height & turbulence	Acoustic sounder	None
Winds, absolute humidity, temperature aloft	Rawinsonde	None
Winds, humidity, temperature & aerosol light scattering coefficient aloft	Tethersonde/Nephelometer	None

5.3 Site Descriptions

5.3.1 Site selection process

A site survey trip was made to the El Paso-Cd. Juarez area in the spring of 1989 to inspect existing and potential new sites for meteorological and air monitoring purposes. Discussions were held with EPA, TACB, El Paso City-County Health District, ASARCO Corp., SEDUE and other contractor representatives. Sites were selected based on such criteria as topography, pollution sources, available facilities (shelter and power), security and personnel access. Final detailed selections were made by the EPA contractor designated to install field instrumentation (this contractor later withdrew from the project before completing instrumentation installation). Sandia acquired towers, meteorological equipment and data acquisition systems for seven sites--five in El Paso and two Cd. Juarez.

5.3.2 Air sampling enhancement at existing sites

Carrying out a preliminary PM_{10} assessment using receptor modeling approaches required that sites be equipped with sampling instrumentation that would provide a suitable data set for subsequent analysis. This study, insofar as possible, made use of existing sites operated by either the City of El Paso or the TACB in order to minimize setup and instrument acquisition costs. Attempts were also made to use existing SEDUE sites in Mexico; however, a survey of these Mexican sites revealed that many existing PM_{10} or meteorological sites did not satisfy the minimum criteria established for such issues as available space, security and proximity to local obstructions. For those sites selected on both sides of the border, augmentation consisted of installation of dichotomous samplers which provide for the separate collection of both fine particle mass (FPM)[1] and coarse particle mass (CPM) aerosol fractions. At selected sites, nephelometers were also installed to give a real-time measure of the aerosol light scattering coefficient, and by inference, aerosol mass concentration. These continuous measurements of aerosol concentration provided a data set from which temporal and spatial variations in pollutant concentrations could be examined. A summary of site names, locations and associated instrumentation is given in Table 10. A topographical map of the area showing site locations is shown in Figure 17. A brief description of each of the sites follows.

5.3.3 General site descriptions

El Paso Airport - Meteorological

The National Weather Service wind set at the airport is mounted on a 10 m mast north of the FAA-NWS Building, which is about 12 km northeast of downtown El Paso. Routine hourly weather observations are taken round the clock and are regularly disseminated through weather communication channels. Exposure (about 40 m above the valley floor) is representative of the flat plateau northeast of town that eventually merges with the Tularosa Basin to the east of the Franklins. ELP is also an upper-air observation station with twice daily radiosondes taken at noon and midnight universal time (0500 and 1700 mst). Rawinsonde balloons are released between 45 minutes to an hour before the nominal observation times. A typical balloon ascent to 10 mb, or 31 km msl (above mean sea level) takes nearly two hours to complete at a balloon ascent rate of 5 ms^{-1}.

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[1] The Fine Particle Mass (FPM) fraction encompasses those particles less than 2.5 μm aerodynamic diameter. The Coarse Particle Mass (CPM) encompasses those particles larger than 2.5 μm and less than 10 μm aerodynamic diameter. Taken together they represent PM_{10}.

Table 10
Winter Season Study Site Locations and Monitoring Equipment

Site Name - Abbreviation	Site Coordinates UTM	Site Elevation m, msl	Site Equipment
Sunland Park, NM - SPK	352552 East 3518673 North	1141	PM_{10} Hivol
Lindbergh, TX - LND	349919 East 3525389 North	1195	PM_{10} Hivol
Vilas School, TX - VLA	357941 East 3514810 North	1100	PM_{10} Hivol
CAMS-12 (UTEP) - UTP	357450 East 3515600 North	1170	PM_{10} Hivol, CO
Northeast - NET	366777 East 3530156 North	1197	PM_{10} Hivol
Ivanhoe - IVN	374670 East 3517550 North	1210	PM_{10} Hivol, CO, Met
Riverside - RVR	369926 East 3511603 North	1120	PM_{10} Hivol
Moon City - MCY	378400 East 3504700 North	1117	Met
Border Patrol - BRP	359380 East 3513390 North	1133	Met
ELP Airport - ELP	368590 East 3519480 North	1195	Met
Fort Bliss - FBL	365080 East 3520950 North	1178	Met
Sun Metro - SUN	357900 East 3514470 North	1138	Dichot, Nephelometer, Met
Tillman - TIL	359620 East 3514400 North	1135	PM_{10}, CO, Met
CAMS-6 - CAM	359270 East 3514980 North	1138	PM_{10} Hivol, Dichots, Denuder, Nephelometer, CO, NO_x, PUF Hivol, Met
Chamizal - CHM	362120 East 3515200 North	1128	PM_{10} Hivol, PM_{10} Beta Gauge, Dichots, Nephelometer, CO, Met, Met Sounding
Ascarate Park - ASC	36690 East 3513790 North	1126	CO
Advance Transformer - ADV	362030 East 3506820 North	1167	PM_{10} Hivol, Dichot, CO, Met
Tecnologico - TEC	367910 East 3509770 North	1123	PM_{10} Hivol, Dichot, CO, Met

Note: The five specially-equipped sites are shown in bold type.

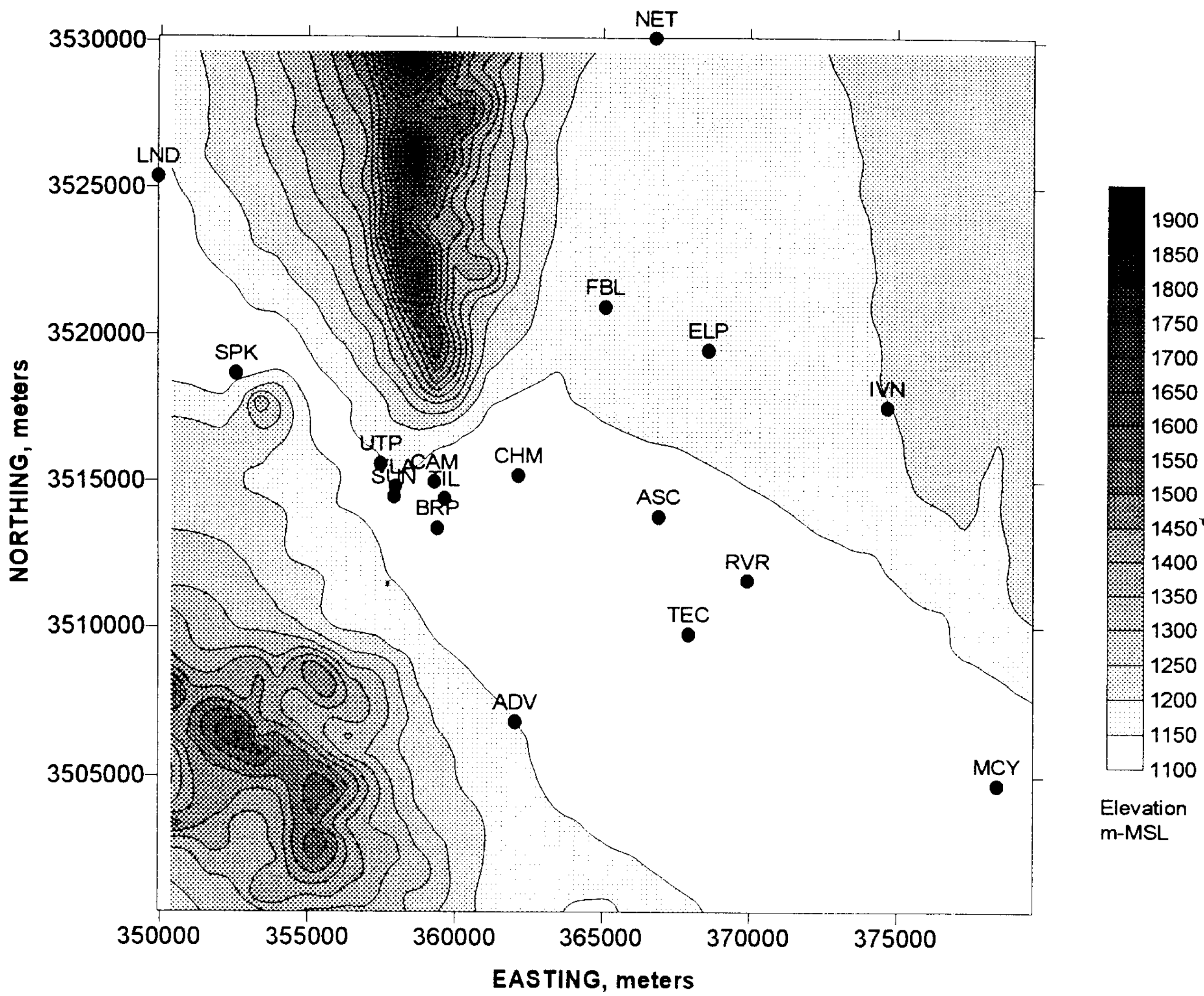


Figure 17 Topographical map of the El Paso del Norte region showing the sampling sites used in the study. See Table 10 for key to site abbreviations.

Sun Metro - Meteorological and Air Sampling

A 10 m tower with wind and temperature sensors and data logger was installed in a fenced storage yard in the extreme northwest corner of the bus yard on the west side of town. Here, the Interstate 10 freeway, and two railroad lines squeeze together to turn from their westerly heading toward the northwest to follow the river course (and hence, border) out of Texas, into New Mexico. The exposure represents the opening of the canyon containing the Rio Grande as it enters the broad valley to the southeast. The site is about 1.5 km west of downtown El Paso and about 2 km east of an active quarry operation located in the northwest outskirts of Cd Juarez across the river. Air monitoring equipment consisting of two dichotomous samplers and an integrating nephelometer were also installed at this site. The dichotomous samplers were positioned on a platform about 1.5 m above ground level since a shelter was not available at this site. The nephelometer was installed in a small unheated shelter adjacent to the dichotomous samplers. The Sun Metro site was selected approximately one week prior to the onset of the air sampling study and came about as a result of an inability to find a suitable site in the southern downtown district of Cd. Juarez. Instrumentation intended for this third met and air sampling site in Cd. Juarez was then moved to the Sun Metro site on short notice.

Border Patrol Building at del Norte Bridge - Meteorological

The US Immigration and Naturalization Service (INS) graciously allowed us to mount wind and temperature sensors on their 15 m communication tower located between the two one-way bridges, about two blocks north of the river, halfway between the downtowns of both cities (one km north and south). The exposure here is now flat, having smoothed out from the slopes at Sun Metro, just 2 km distant to the northwest.

Fort Bliss - Meteorological

The US Army allowed us to install a 10 m tower in a yard on their post at Fort Bliss. This site is about 4 km northwest of the airport site and about 9 km north-northeast of downtown El Paso. The exposure is flat, just at the edge of the plateau before it ascends toward the Franklin Mountains' ridge line 6 km to the west.

Ivanhoe Fire Station - Meteorological and Routine Air Sampling

The El Paso City-County Health District borrowed two crank-up towers from El Paso Natural Gas Company and arranged for one to be installed at the Ivanhoe Fire Station in the far northeast part of the El Paso. The site is located about 6 km east-southeast of the airport site and about 16 km east-northeast of downtown at the southwest corner of Ivanhoe and Lee Trevino Drives. The elevation, at 1210 m msl, is the highest of the installed stations. The exposure is flat in all directions with only residential and small commercial buildings in the vicinity. In addition to the meteorological equipment, instruments for CO, O_3, and PM_{10} were routinely operated by El Paso City-County personnel at this site.

Moon City Clinic - Meteorological and Routine Air Sampling

This El Paso site was at the City-County Health Clinic in the far southeast valley some 21 km southeast of downtown El Paso. The site is in valley bottom land, about 4.5 km northeast of the Rio Grande at an elevation of 1117 m msl (the lowest elevation site in the study) near the intersection of North Loop Road and Old Hueco Tanks Road. The other borrowed tower was installed next to the building, through a tree, which should not seriously compromise the wind measurements at the low wind speeds which are of most interest in this project.

Instituto Tecnologico de Monterrey - Meteorological and Air Sampling

This Cd. Juarez site is on the campus of the Instituto Tecnologico y de Estudios Superiores de Monterrey (Campus Juarez), near the corner of Avenida A. J. Bermudez and Avenida Tomas Fernandez, about 0.5 km due south of the Hipodromo-Galgodromo (Juarez Race Track). It is in eastern Cd. Juarez, about 10 km southeast of downtown El Paso. The exposure is flat bottom land with many one story maquiladores buildings in the vicinity. In addition to the 10 m weather tower, PM_{10} and dichotomous samplers were positioned on site along with a trailer containing CO and O_3 continuous monitors.

Advance Transformer Co. - Meteorological and Air Sampling

This Cd. Juarez site is about 6.5 km south-southeast of the downtown section near the intersection of Calle El Cid and Calle Beckett just off Calle Magneto. The site was located on the north side of the Advance Transformer Co. maquiladora at an altitude of 1167 m msl, about half way between the Rio Bravo and Sierra Juarez crest to the southwest. The exposure is characterized by many one story buildings on gently sloping ground whose fall line aims toward the east-northeast. The area is surrounded by maquilas and small tile/brick kilns which at times were observed to emit copious quantities of smoke. Continuous monitors for ozone and carbon monoxide as well as a hivol PM_{10} sampler were also located at this site. For this short term study, the site was also augmented with two dichotomous samplers with quartz and teflon filter media.

Chamizal National Memorial Park - Meteorological and Air Sampling

This site, on the north side of the Rio Grande just 3 km east-northeast of downtown El Paso at an altitude of 1128 m msl, is on park land formerly known as Cordova Island. The exposure here is superior in that no structures of consequence are within at least 1 km in any direction, and the terrain is quite flat near the river bottom. The El Paso City-County Health District maintains an air monitoring site here that includes a meteorological tower, a hivol PM_{10} sampler, a beta-gauge PM_{10} sampler and continuous monitors for ozone and carbon monoxide.

Personnel from the Atmospheric Sciences Laboratory set up a 10 m tower at Chamizal Memorial which included UVW propeller anemometers at 10 and at 2 m, thermometers at 10 m, 2 m, surface and soil (-0.05 m) as well as a radiometer (PSP). Data were taken on a Campbell data logger in 15 minute intervals. A Remtech acoustic tri-axial doppler acoustic sounder (or SODAR - sound detection and ranging) was placed about 25 m away from their tower to give wind profiles up to about 1000 m agl. Some problem was experienced with this unit, however, because of the presence of the nearby Border Highway which contributed substantial background noise interference and limited the sounder's range. The data from the ASL system were later supplied to Sandia in hardcopy and diskette form.

Sandia personnel set up a portable radio theodolite unit (AIR Inc., "Intellisonde") to take soundings during selected periods of the two-week measurement interval. Normally, sounding balloons were released at 0800 and 1200 mst to better define atmospheric stability and upper air flow in the period between the 5 AM and 5 PM NWS soundings, as well as to cover the additional vertical profile from valley bottom to airport plateau top, 37 m higher. Data from this system were telemetered, processed and recorded every 5 seconds to about 10,000 m msl.

A helium-filled tethered balloon known as a tethersonde (AIR Inc.) equipped with a meteorological sensor package and a Sandia-designed integrating nephelometer was also operated at the Chamizal site. The sensor package was winched up to a maximum profile height of 250 m agl as allowed by FAA regulations. Flights started at sunrise and continued until about 1400 mst (except the first day when they went until sunset). About 90 minutes were required to complete a calibration and round trip profile. Measurements of pressure, temperature, humidity, wind direction, wind speed and aerosol light scattering coefficient were telemetered to the ground receiver and recorded to disk file at 5 s intervals.

The Chamizal site was also augmented with two dichotomous samplers with Teflon and quartz filter media and an integrating nephelometer equipped with a heated inlet. Data acquisition at this site was accomplished using an existing City-County system and a separate data logger for the nephelometer.

CAMS6 - El Paso

The Continuous Air Monitoring Station 6 (CAMS6) is one station in a network of Texas Air Control Board air sampling sites located across the state of Texas and was the most extensively equipped site in the study. This site is located on the northeast edge of the downtown El Paso district near the intersection of Campbell Street and Interstate 10. Instrumentation on the roof of the shelter included a meteorological tower and associated sensors, PM_{10} samplers, two automated dichotomous samplers with quartz and teflon filter media, an additional dichotomous sampler for microscopy study, annular denuder samplers and a high volume sampler equipped with a PUF cartridge for semi-volatile organic sampling. Samplers inside the shelter included continuous monitors for sulfur dioxide, carbon monoxide, oxides of nitrogen, ozone and a nephelometer.

Air quality and wind measurements were also available at two other TACB continuous monitoring sites--one at Ascarate Park (CAMS-30), 8 km east of downtown, and the other at UTEP (University of Texas - El Paso, CAMS-12). Wind data were also obtained from the ASARCO Company's Executive Center 30 m tower, 5 km northwest of downtown; and from the New Mexico Department of Environment's Sunland Park station (6ZG), 8 km northwest of downtown, northwest of the Sierra de Cristo Rey, in the south end of the Mesilla Valley.

5.4 Study Results

5.4.1 Meteorological Measurement Results

5.4.1.1 Description of the overall meteorology during the study interval

The synoptic weather maps during the first week of December showed a large surface high pressure system centered over the Southwestern US (Great Basin and southward along the Continental Divide) with only weak easterly surface winds over southern New Mexico and far west Texas. The flow aloft was dominated by a broad ridge of high pressure over the Continental Divide area which kept many short wave disturbances well to the north. Skies were clear, and winds were light, which is the "ideal" situation for air stagnation conditions to begin and persist. This stable meteorological situation prevailed until December 11, when a low pressure trough aloft approached the region from the west causing the ridge to collapse and the winds to increase, thereby ventilating the valley. High winds also made flying tethered balloons hazardous as a result of power lines adjacent to the Chamizal site. For the next two weeks many short wave disturbances traversed the area causing unsettled weather until just after Christmas. However, as noted above, the meteorology on December 8-10 produced intense stagnation conditions which caused enhanced pollution concentration.

5.4.1.2 Typical network winds during the stagnation period

As was expected, the behavior of the near surface winds strongly depended upon location. At Sun Metro the wind was nearly always from the northwest as air drained out of the Mesilla Valley through the pass. Figure 18 shows the direction and speed curve for the 7th through 11th. Notice the direction hovering around 310° except during the afternoons of the 7th and 8th when a more south and southwesterly direction prevailed until 1800 hours each evening when drainage flow resumed. The dichotomous sampler at Sun Metro showed its highest concentration during the evening of the 8th after the direction had been averaging southwesterly for over 6 hours and the speed decreased from three to two to one ms^{-1}. A notation made by a technician in a log book that evening while at that site to service some equipment reads "...very murky!"

At Tecnologico, away from immediate terrain influences, the direction variability was extreme. See Figure 19 for a plot of direction and speed from this station. Speeds were nearly always less than 2 ms^{-1} until 0600 on the 11th as they started to increase toward 6 ms^{-1} by 1600 mst. At Advance Transformer there was slightly more order as can be seen from Figure 20. Here the wind speed, again less than 2 m s^{-1} until the 11th, tended to come from the southeast in the morning and swing around from the west and northwest by evening and night. This picture fit with the expectation of upslope flow when the sun shines on the eastern slope of Sierra Juarez in the morning, followed by down slope drainage as the sun moves to the west side of the range by evening. In general, variable wind directions are to be expected during periods of light winds.

For Chamizal, a pair of plots showing temperature/humidity and wind direction/ wind speed are shown for the 24-hour period from midnight to midnight on the 8th in Figure 21. The speed here rarely exceeded 1 m s^{-1}, but the sensor was a UVW triaxial propeller set whose direction cosine response may be questionable, especially at low speeds. After about 0015 mst the direction, with an indicated speed of less than 0.5 m s^{-1}, veered slowly from east through south through west through north to northeast by 0300 where it remained, with a speed of slightly greater than one 1 m s^{-1} until 0630. From about 0700 until 1730 flow was variable from the south, backing around to northeast by 1745. Figure 22 shows sodar winds at heights of 100 and 150 m above ground. These data show the generally northerly (between northwest and northeast) flow until about 0600.

5.4.1.3 Sounding data from Chamizal tether- and rawin-sondes

Figure 23 shows temperature sounding data for midmorning of the 8th from both the radiosonde to 6000 m msl, and the tethersonde to 250 m agl (above ground level) respectively. The latter plot essentially fits inside the bottom rectangular grid box of the radiosonde plot. The agreement is quite satisfactory. The data for the 8th are being emphasized here because, as discussed later, that is the day selected to test the Diagnostic Wind Model. In general, the radiosonde profile shows marked stability (inversion) to about 822 m agl with less stability to 2500 m agl (3630 m

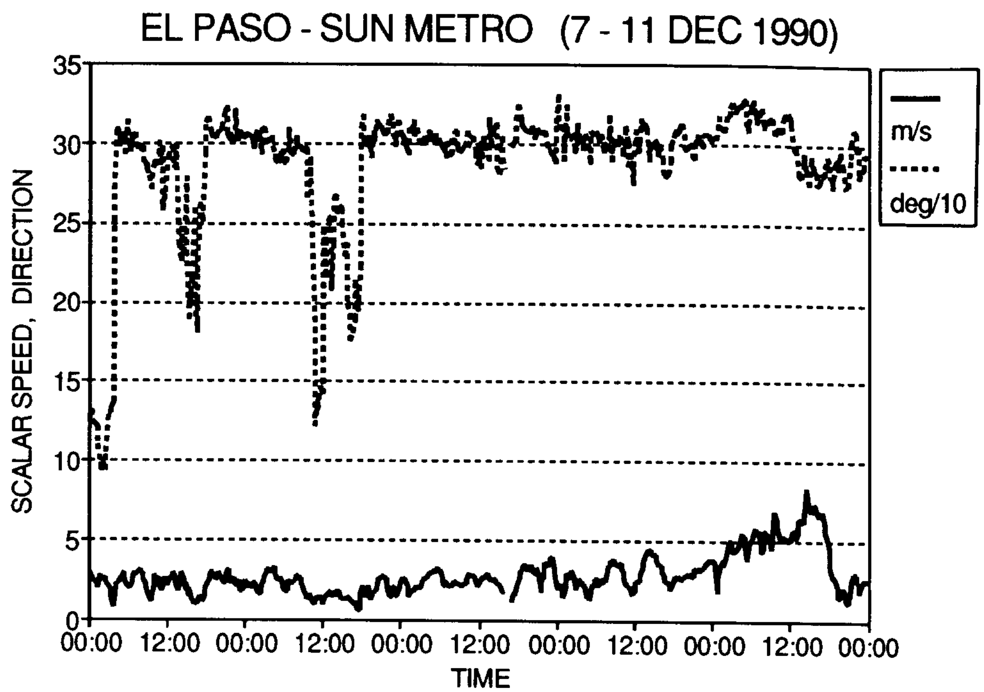


Figure 18 Wind speed and direction for December 7-11 at the Sun Metro site.

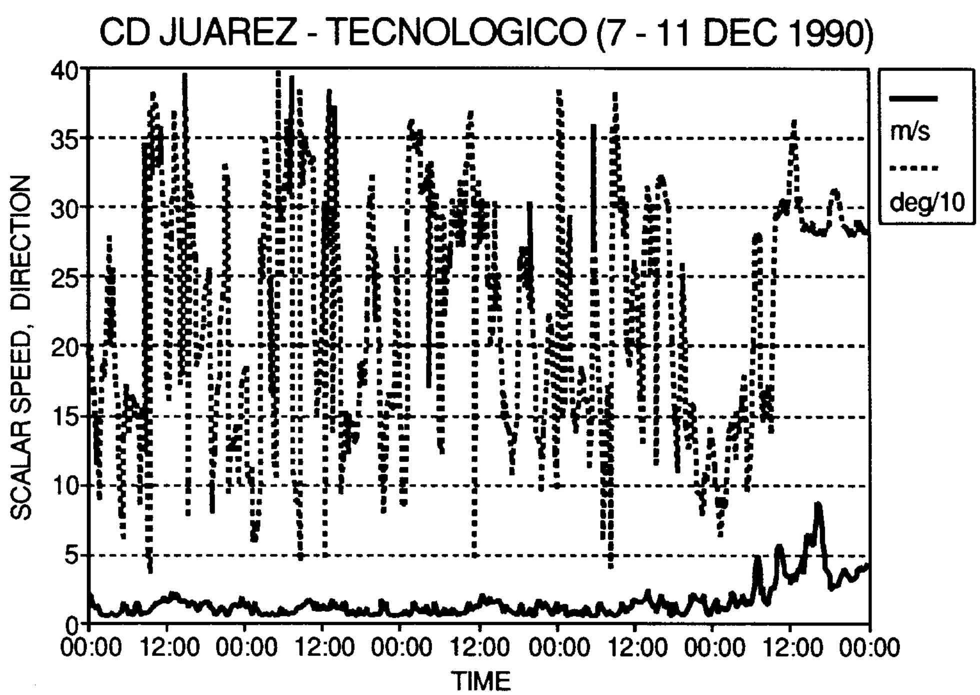


Figure 19 Wind speed and direction for December 7-11 at the Tecnologico site.

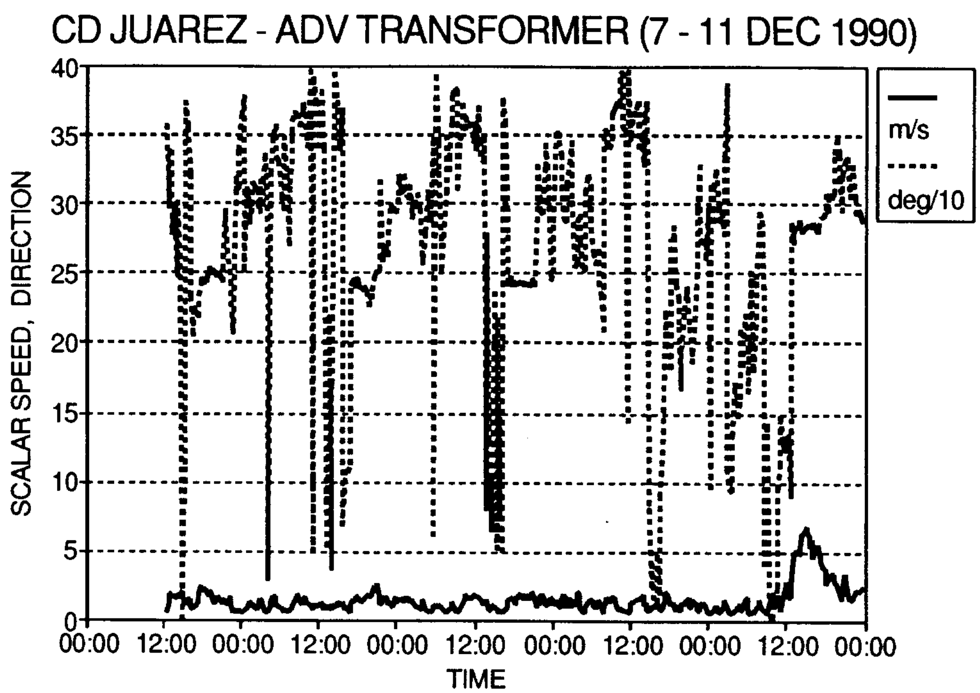
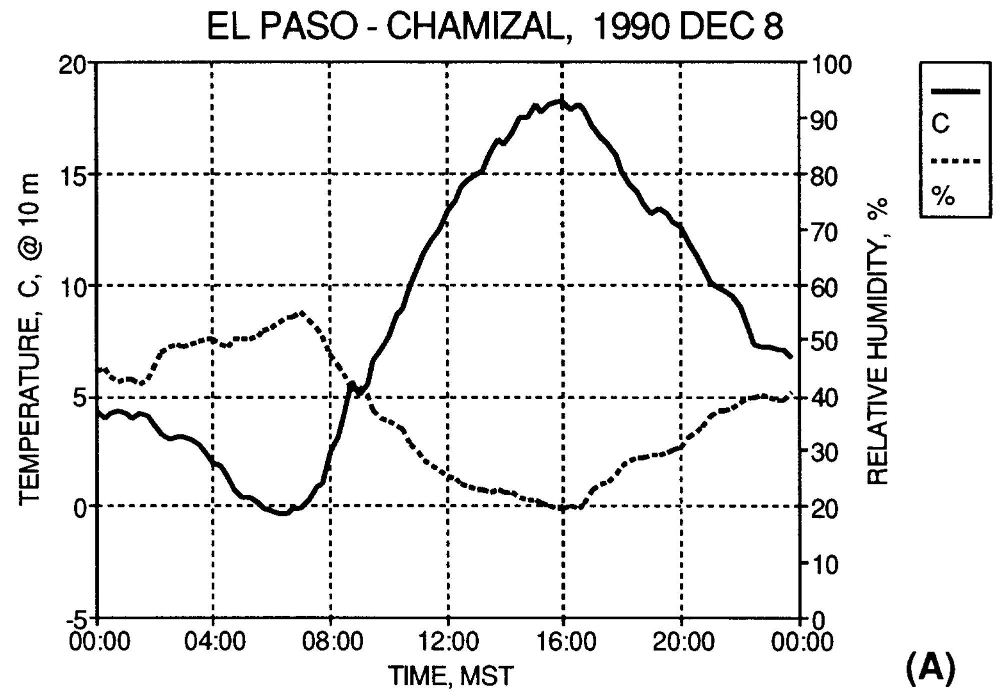
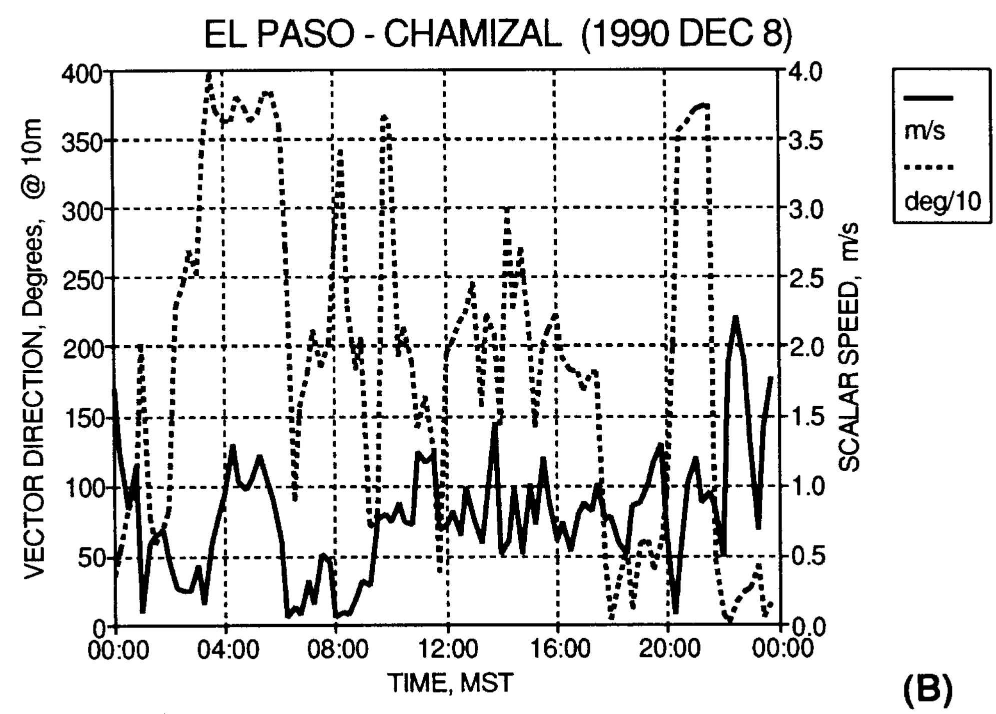


Figure 20 Wind speed and direction for December 7-11 at the Advance Transformer site.



(A)



(B)

Figure 21 Temperature/humidity (A) and wind speed/wind direction (B) for December 8 at the Chamizal site.

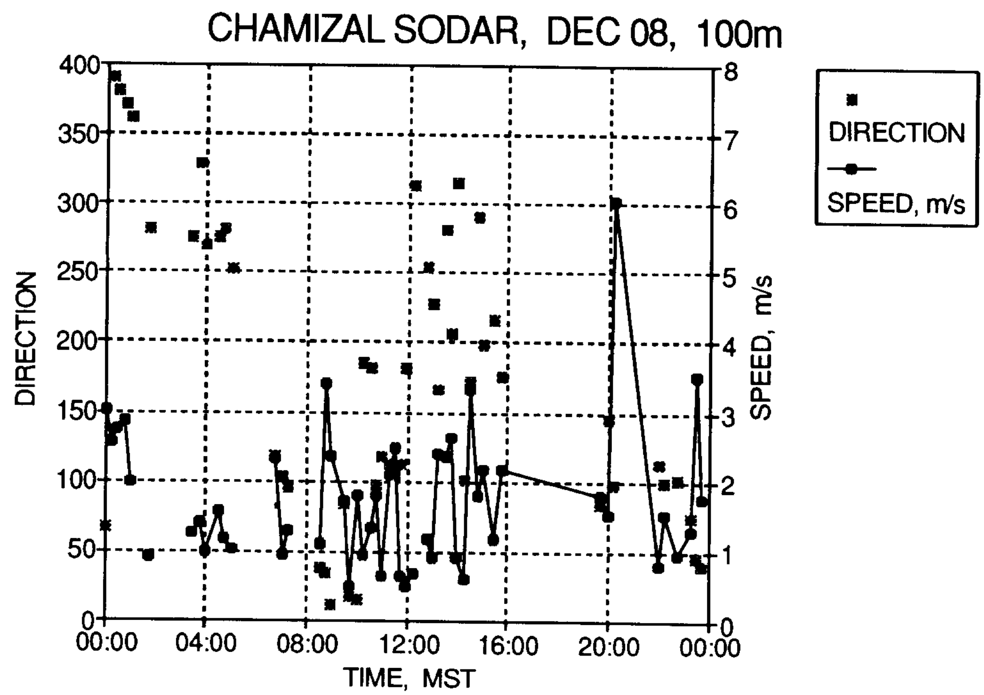
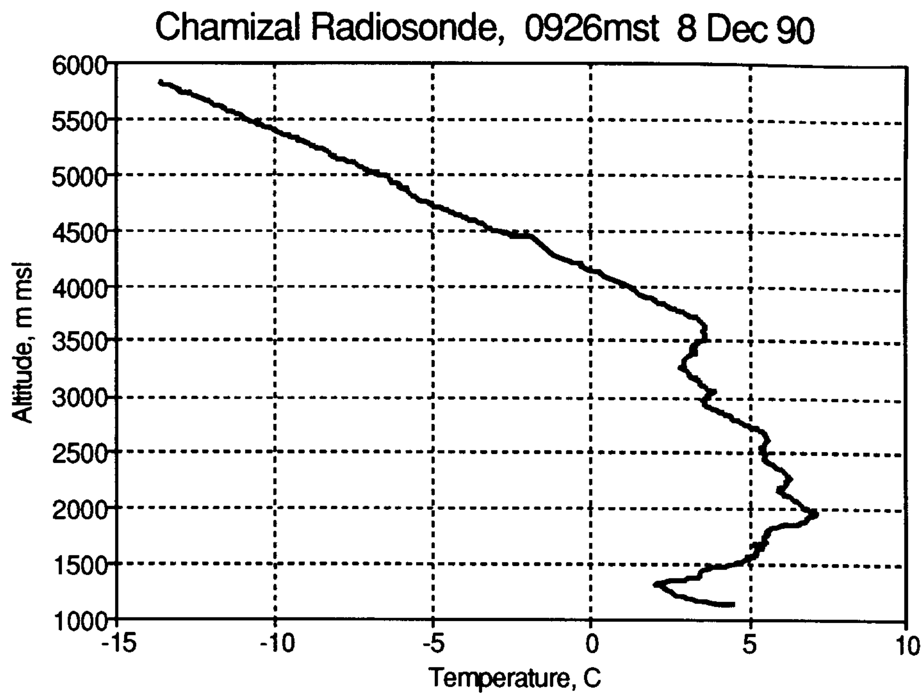
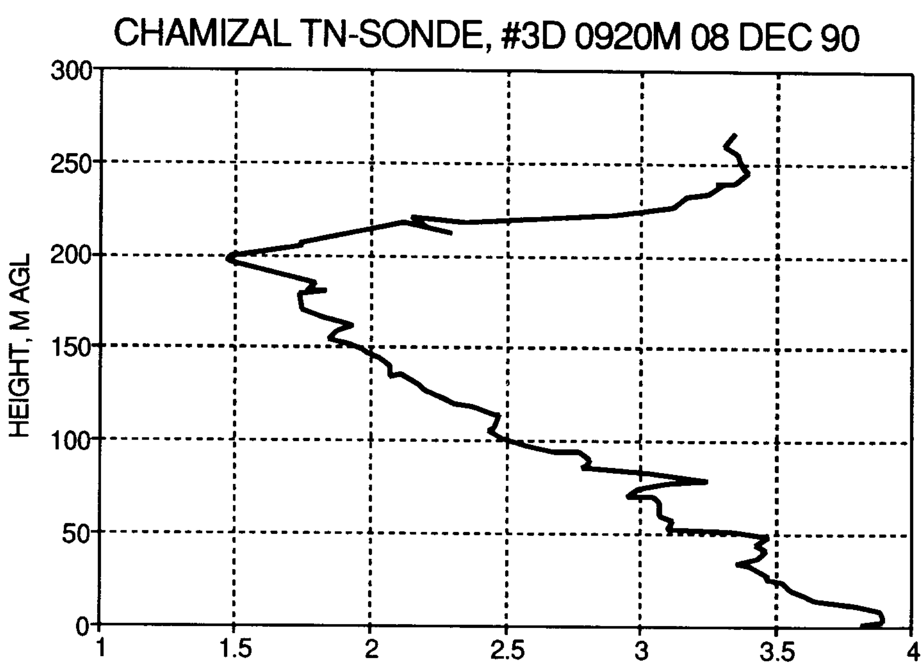


Figure 22 Sodar measured winds on December 8 at the Chamizal site.



(A)

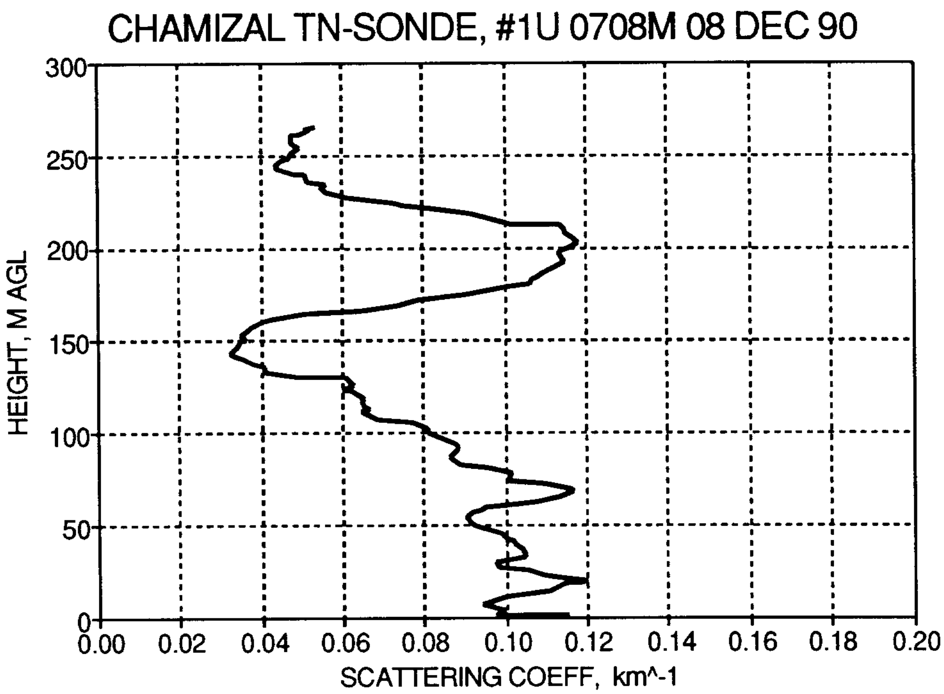


(B)

Figure 23 Chamizal temperature sounding data from the morning of December 8 from radiosonde (A) and tethersonde (B).

msl). The profile above this is closer to neutral at a lapse rate of about 8.0 °C(km)$^{-1}$ (the neutral adiabatic process lapse rate is 9.8). Much detail can be seen in the stratification which is typical of stable profiles.

Figures 24 through 31 show scattering coefficient profiles from the balloon-borne nephelometer for both ascending (U) and descending (D) traverses of the tethersonde taken throughout the day. Typical clean air values are less than a 0.01 km^{-1} whereas late in the day values approached 0.06 km^{-1}. (The apparent height displacement of the elevated peak between the two profiles of Figure 24 is judged to be a response-time effect as the instrument was reeled up or down during the runs). A complete listing of all radiosonde and TN- (tethered nephelometer) sonde flights made during the intensive measurement period is listed in Table 11.



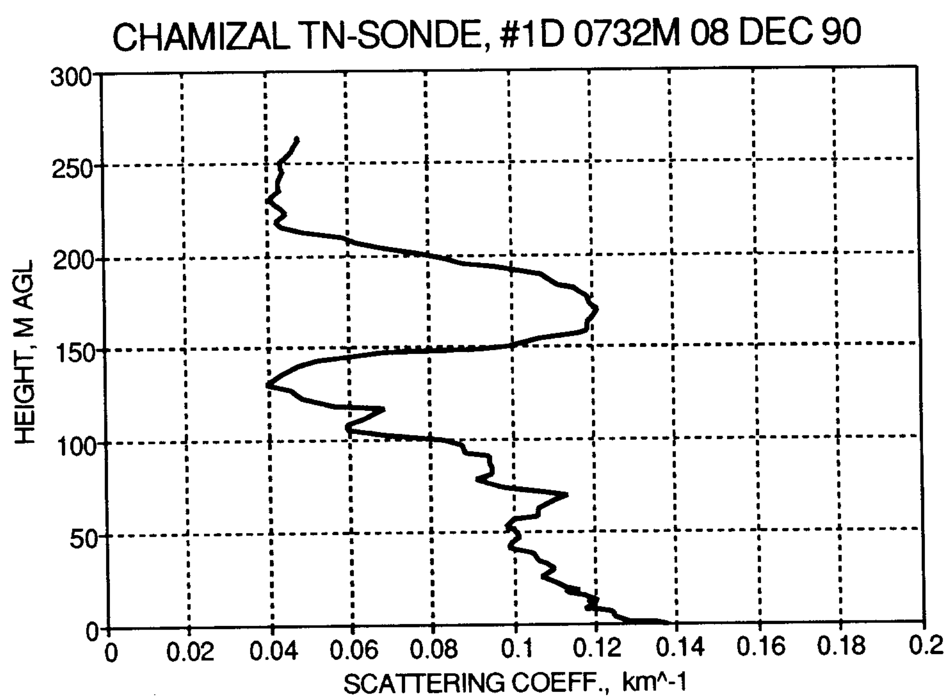


Figure 24 Scattering coefficient profiles during balloon-nephelometer ascent (upper) and descent (lower) during 0708-0732 hours on December 8 at the Chamizal site.

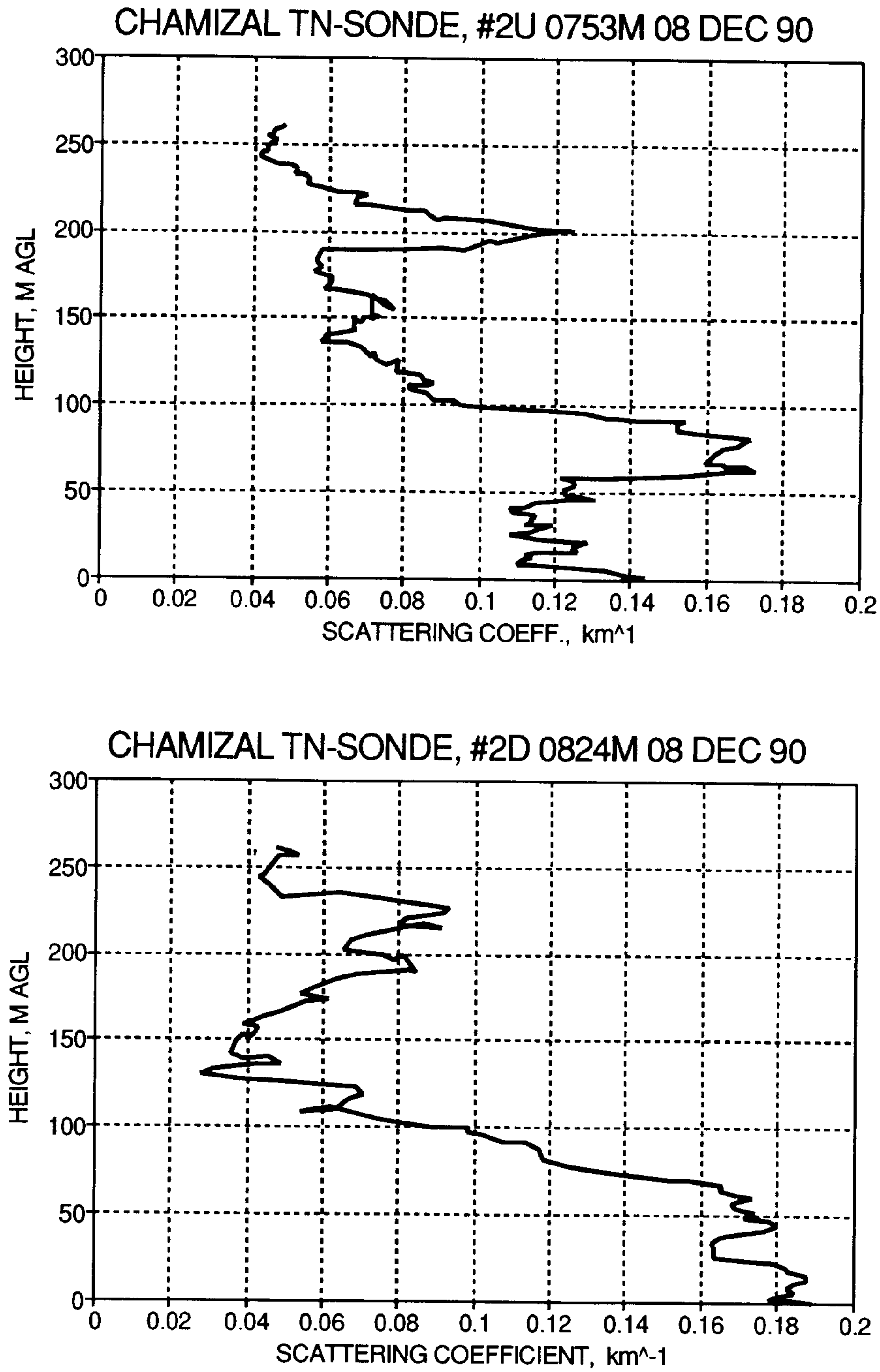
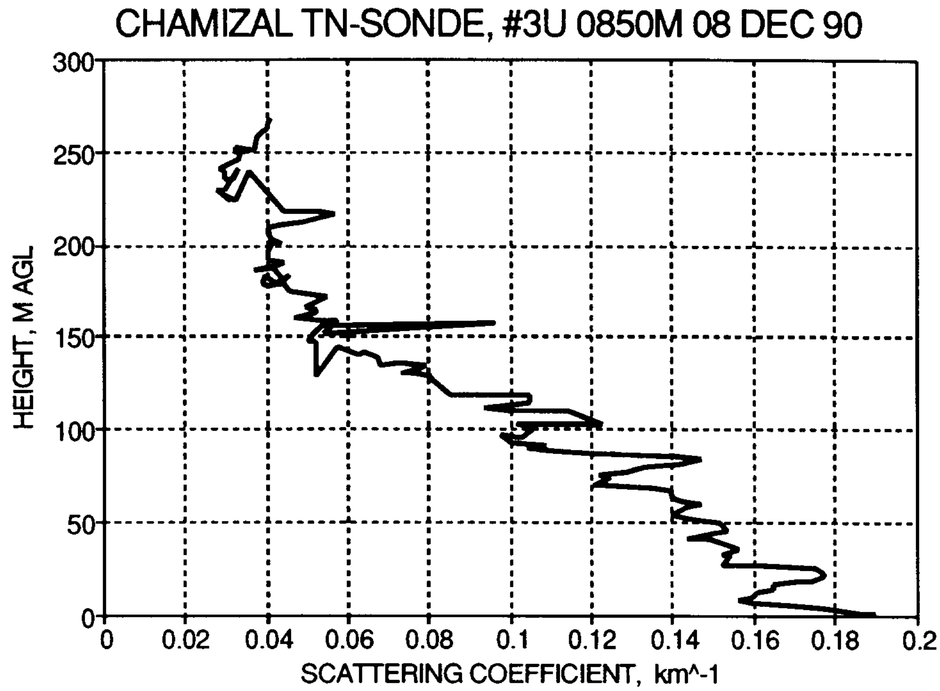


Figure 25 Scattering coefficient profiles during 0753-0824 hours at the Chamizal site.



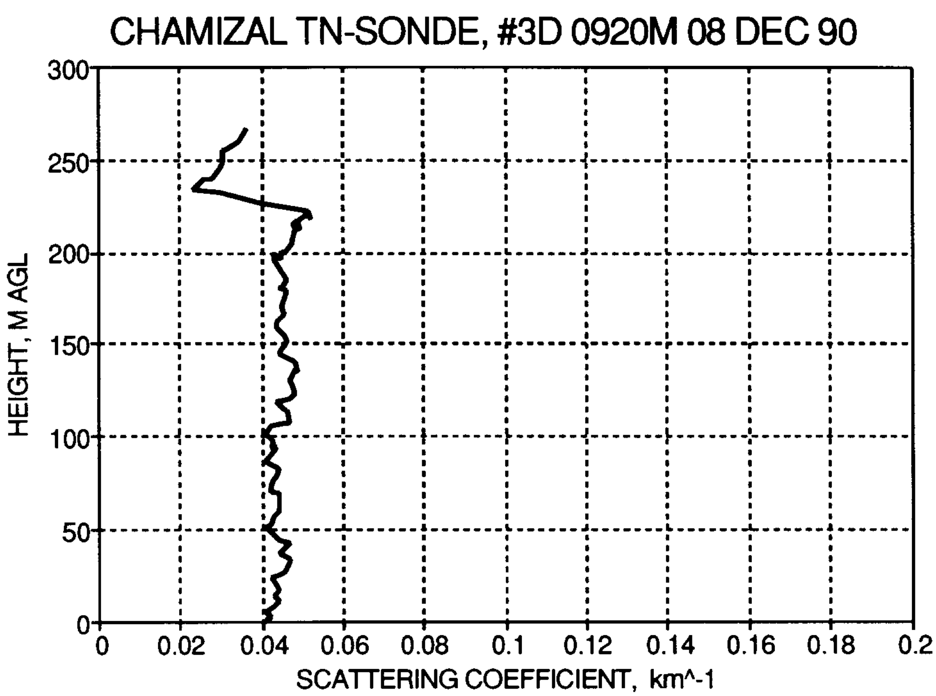


Figure 26 Scattering coefficient profiles during 0805-0920 hours on December 8 at the Chamizal site.

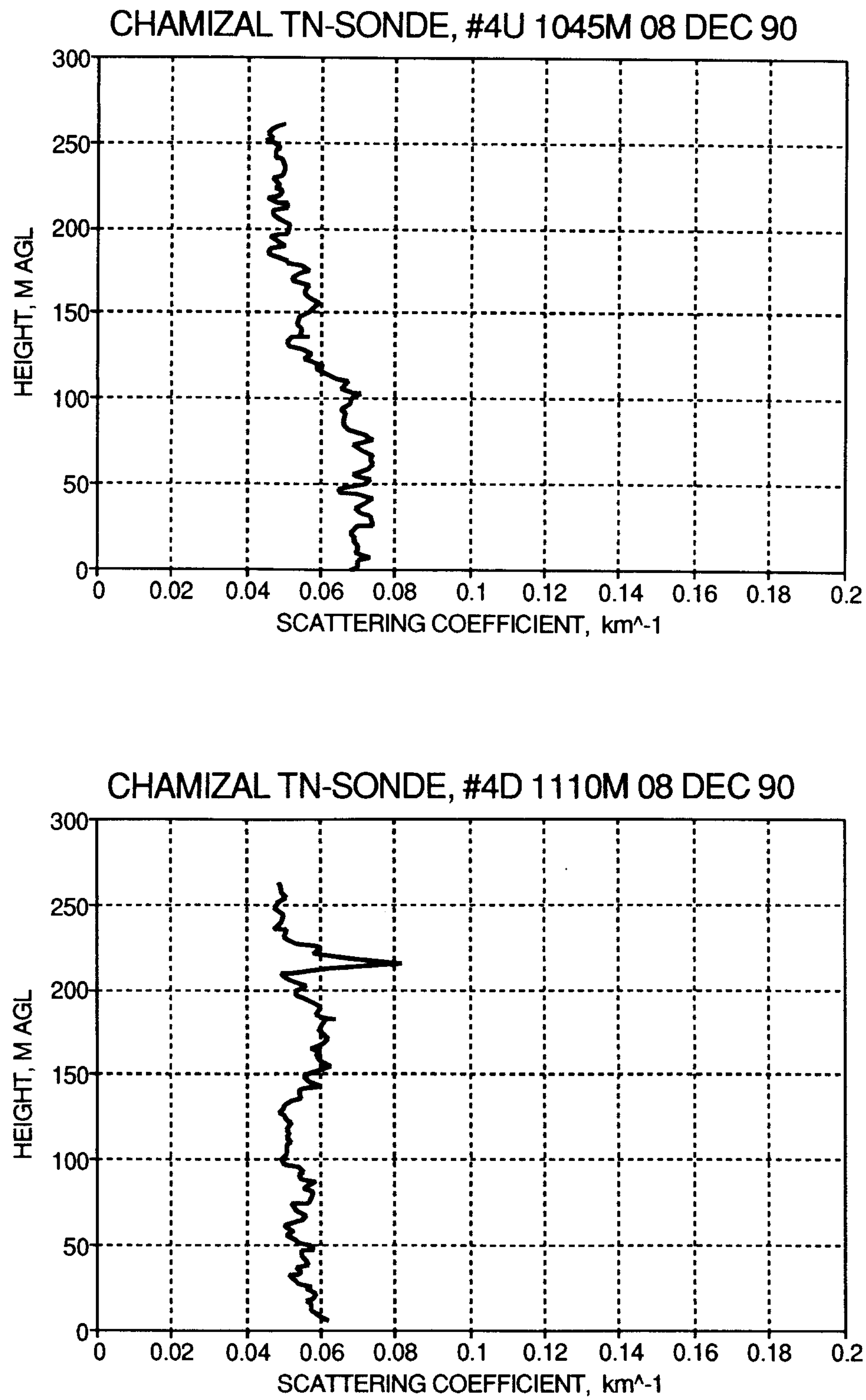
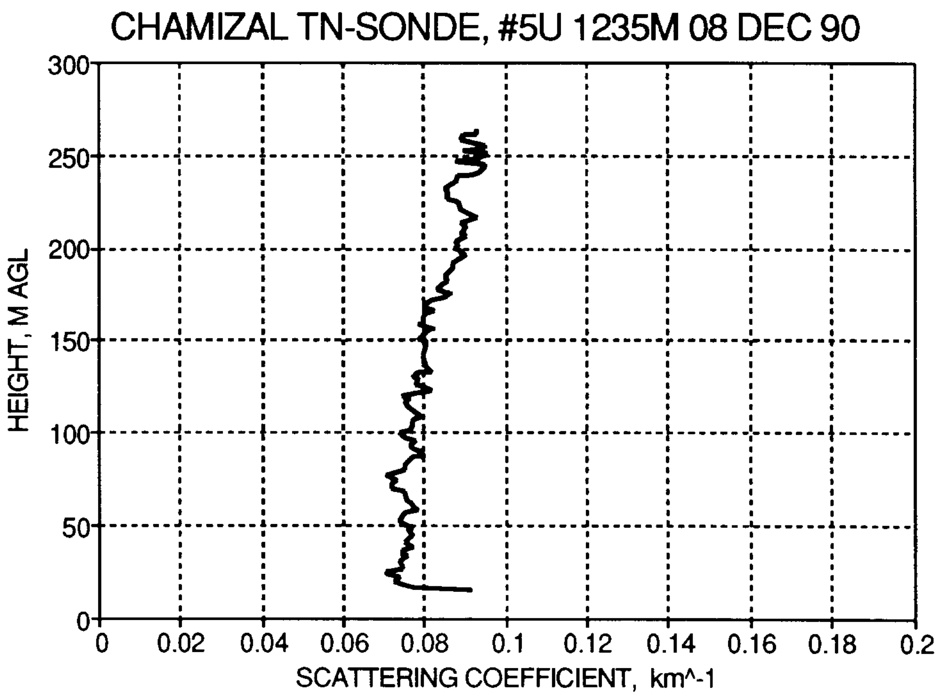


Figure 27 Scattering coefficient profiles during 1045-1110 hours on December 8 at the Chamizal site.



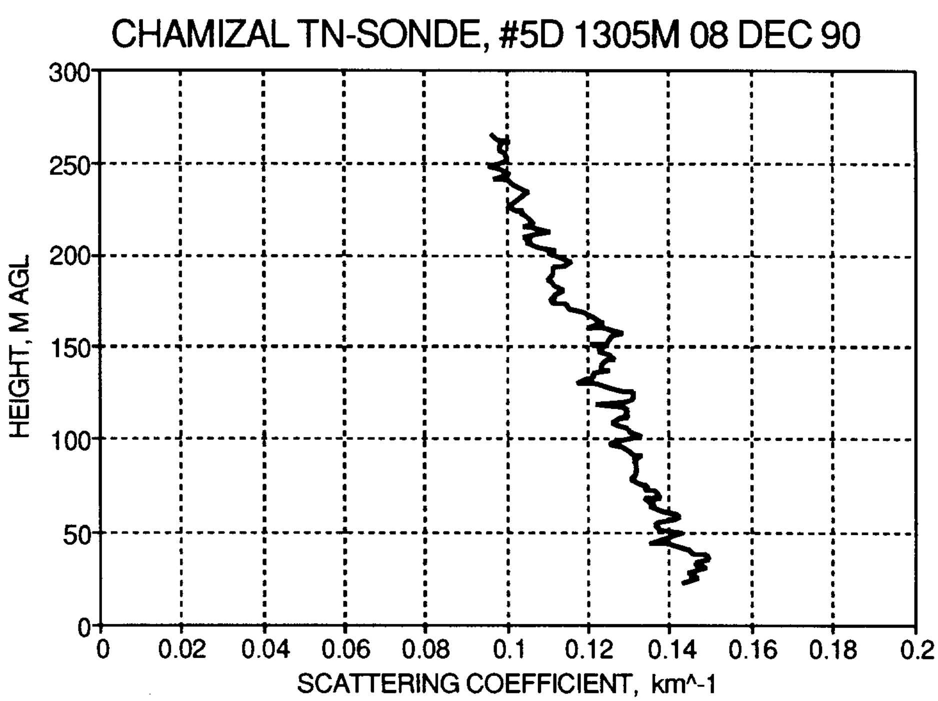
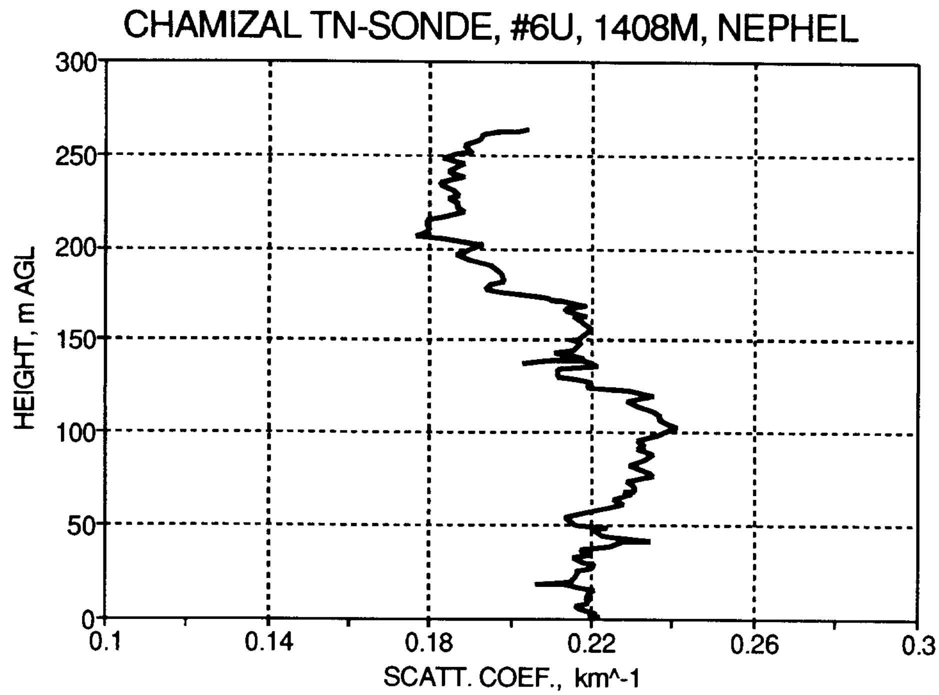


Figure 28 Scattering coefficient profiles during 1235-1305 hours on December 8 at the Chamizal site.



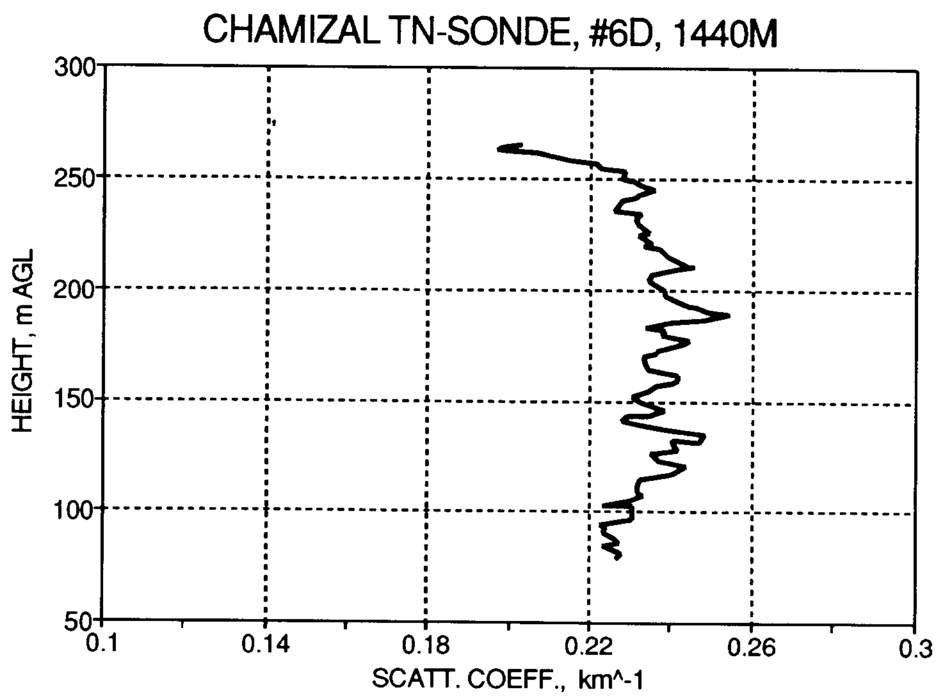


Figure 29 Scattering coefficient profiles during 1408-1440 hours on December 8 at the Chamizal site.

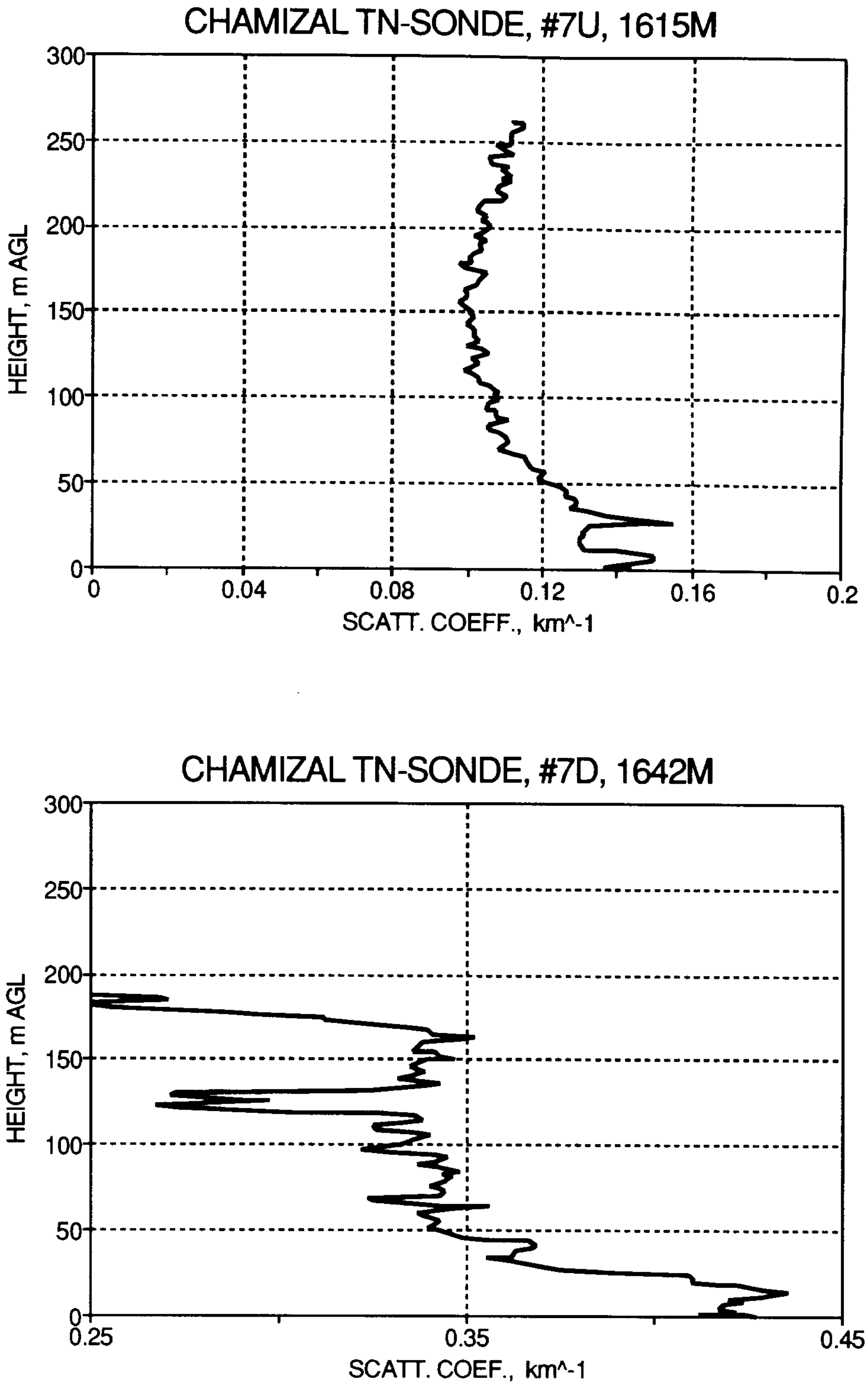
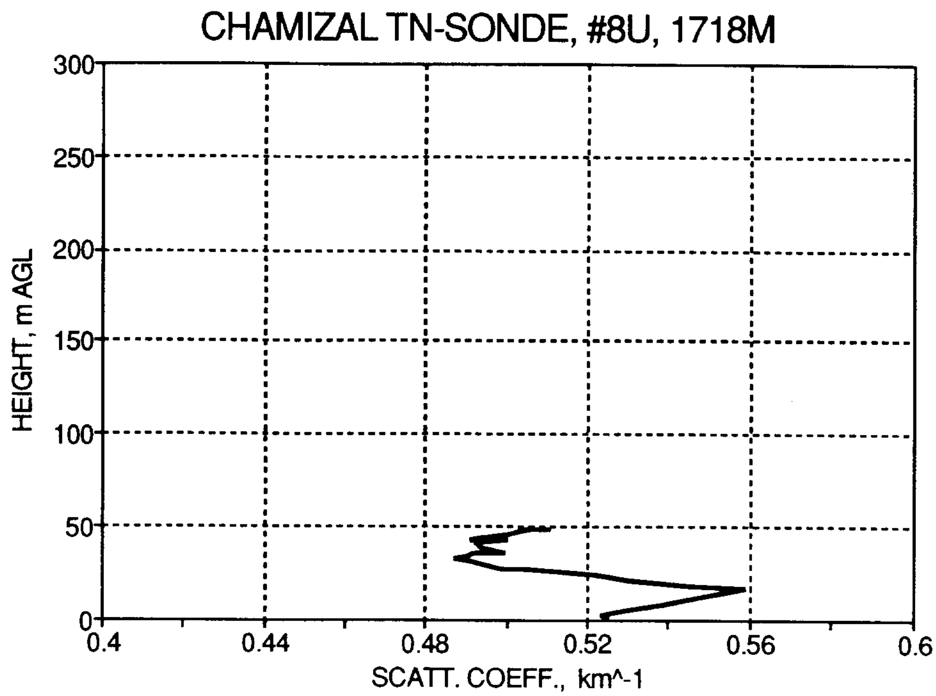


Figure 30 Scattering coefficient profiles during 1615-1642 hours on December 8 at the Chamizal site.



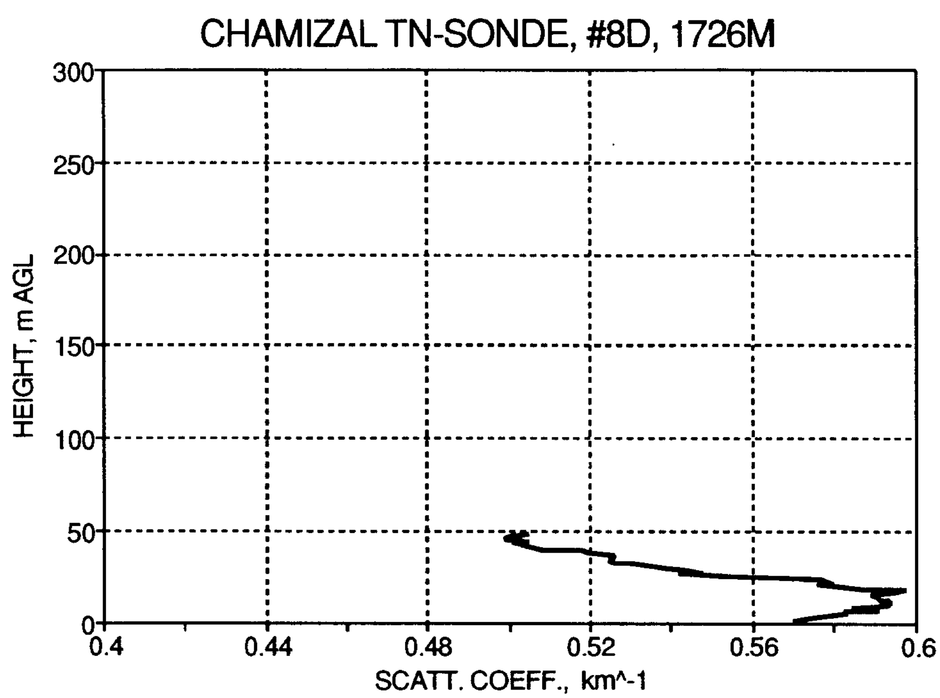


Figure 31 Scattering coefficient profiles during 1718-1726 hours on December 8 at the Chamizal site.

Table 11
Tethersonde and Radiosonde Soundings at the Chamizal Site on Dec 8-10, 1990

Date	Ascent/Descent No.	Start Time	Stop Time	Max. Altitude m
Dec 08	1U	706	727	265
"	1D	733	749	
"	2U	753	820	261
"	2D	824	842	
"	3U	850	914	268
"	3D	920	936	
"	4U	1045	1104	262
"	4D	1110	1130	
"	5U	1235	1257	264
"	5D	1305	1330	
"	6U	1408	1430	264
"	6D	1440	1455	
"	7U	1615	1634	263
"	7D	1642	1707	
"	8U	1718	1723	49
"	8D	1726	1732	
"	Radiosonde	926	1050	13500
"	Radiosonde	1259	1400	9477
Dec 09	1U	701	725	255
"	1D	728	748	
"	2U	803	828	254
"	2D	830	851	
"	3U	855	916	254
"	3D	920	935	
"	4U	958	1019	265
"	4D	1024	1045	
"	5U	1018	1133	258
"	5D	1138	1159	
"	6U	1210	1235	255
"	6D	1240	1254	
"	Radiosonde	812	844	5358
"	Radiosonde	1200	1246	7789
Dec 10	1U	705	727	264
"	1D	730	749	
"	2U	811	843	263
"	2D	850	843	
"	3U	920	945	263
"	3D	951	1023	
"	4U	1057	1117	273
"	4D	1120	1145	
"	5U	1159	1223	261
"	5D	1223	1247	
"	Radiosonde	809	1001	21680
"	Radiosonde	1159	1326	15277

Various minor problems crept into the operations to prevent 100 percent data recovery (sonde battery failure, computer software hangups, keyboard malfunction in cold, subfreezing environment), but a rough qualitative estimate is that better than 95 % data retrieval was achieved.

The elevated scattering layer at about 200 m msl in Figures 24 through 26 is somewhat of a puzzlement as to possible origin. It is too high to have come off the northeast heights of El Paso as drainage. Actually, the layer at 70 m agl may have come from this source since, as mentioned above, there were several hours of light northerly wind in the morning before this profile was measured. The 200 m layer is 64 m below the actual ASARCO stack top, and plume stabilization is probably about 10 m higher than stack top. However, in the 6.5 km straight line distance from the stack to Chamizal it is possible for some settlement to have occurred, or some downward flow motion could have occurred in response to the diverging easterly wind flow caused by terrain features below. A look at the wind direction for 1330 m msl from the radiosonde released at 0926 shows it to be from 030°.

The variability in aerosol scattering coefficient from profile to profile is striking. Profile 7D is of questionable validity as the tethersonde battery failed shortly after starting descent. Prominent features to be noted are: disappearance of the 200 m agl layer by 0850; cleansing of the entire profile by 0920 as a result of increasing mixed layer (supported by following profiles); buildup of values after 1300 (note scale shifts); and very large values near ground level by sunset. (Balloon flying above 50 m after sunset was disallowed, hence the truncated #8 profile). High aerosol scattering values (0.45 km^{-1}) were also seen on the nephelometer located in the adjacent shelter.

5.4.2 Diagnostic Wind Field Model Runs

5.4.2.1 Diagnostic Wind Model Description

EPA-6 requested that Sandia look at the Diagnostic Wind Model (DWM), a component part of the larger Urban Airshed Model (UAM) used for oxidant modeling as part of the SIP generation process. This submodel, prepared by SAI over many years, is a diagnostic, as opposed to a prognostic, formulation which calculates wind flow over complex terrain using a network of surface and upper air wind observations. Prognostic models generally contain a more comprehensive suite of physics formulations which enable a realistic forecast of flow over complex terrain. The latter generally requires fewer input observations than diagnostic approaches. However, the complexities involved in a prognostic model usually mean an enhanced cost of development and operation over a diagnostic approach.

For application to the El Paso situation a 1:100,000 topographic map was studied to best locate a computational domain that would include all areas of interest, observation points and influential terrain features. A 30 x 30 km square was marked out which best appeared to fill these criteria and that fell on even metric grid blocks of the UTM (Universal Transverse Mercater) grid system for the area. The grid domain is shown in Figure 1. A 40 x 40 grid of 750 m interval was chosen with 14 layers in the vertical as being an acceptable resolution for faithfully representing the terrain which did not overwhelm the computer memory and computational resources. Vertical grid spacing varied from 25 m near the ground to 200 m at the top (1500 m agl). A digital tape file of terrain data for the El Paso region and some associated processing software was received from EPA contractor Lockheed Engineering & Sciences Co., Las Vegas, NV, at the request of Region 6.

The model is formulated in terrain-following coordinates which allows computation of wind vectors at constant heights above ground using conservation of mass (only) principles. Input data required are: grid description, gridded terrain heights and type, domain-mean winds, domain-scale stability (dT/dz), and actual surface and upper air wind observations. The model generates gridded component (westerly, U, and southerly, V) winds in a two step procedure. A domain mean wind is adjusted for kinematic effects of terrain forcing, thermodynamically generated slope flows and blocking effects producing a spatially-varying, mass-consistent, gridded field for each specified vertical layer. The second step incorporates the addition of actual wind observations to the step one domain averaged field. A specified radius of influence for observations is set by the user, such that the domain mean is used outside the influence radius where observations are lacking. Details of the procedures used in the code are given in published code documentation [EPA,1990].

Processing of surface and upper air data are handled by separate preprocessing routines which require information about number, identifier and location of stations; starting and ending time; hourly direction and speed for surface data; and observation time and height for upper air data. Values are interpolated spatially and temporally to provide inputs for each model level for each hour of simulation. The resulting processed data are then written to separate files which are read incrementally by the wind model. Another input file is prepared which contains the many control options and parameters needed (over 40 are listed in the manual). It is clear that the best combination for these parameters would take many experimental runs to optimize.

Output from the DWM is a series of tables of component wind values for each level and grid point. These tabulated values were input to a post-processor package on a PC (Surfer®, Golden Software, Boulder, CO) which produced graphic vectors at each grid point showing direction and speed class for various pre-selected hours. Results for one of the selected stagnation days are shown later.

5.4.2.2 Selection of DWM test day

Of the three days comprising the intensive measurement period (8th, 9th and 10th), the 8th was selected as the most interesting single day for DWM performance evaluation. This judgement was based on completeness of data records and elevated nature of ground monitoring data of both particulate material and gas monitors.

5.4.2.3 DWM Model results

The required input files for the DWM were prepared from the wind data then available (excluded were data from Sunland Park, Executive Center, CAMS- 6, -12 and -30 that are now available and will be included at a later date). Reformatting of the various data records into that required was done by hand since three different formats were involved. The three yet unused groups mentioned above are even different still. The DWM code had been installed on a VAX 8700, and later moved to a VAX 3800 (Micro VAX) for reasons of economy. A typical run took approximately 45 minutes on the 786, and roughly twice that on the Micro; however, per run charges were avoided on this smaller computer.

A rigorous evaluation of the model's performance is beyond the scope of this report, however some general observations about its performance can be made. The output from the code is a series of tables displaying U and V wind components at each grid cell for each height layer. These files mentioned above to produce graphical output. Figures 32-37 show vector wind categories for selected heights above terrain and hours of the day for each grid cell. In addition, elevation contours are shown at 30 m intervals. In general, the vectors behave in a logically intuitive fashion: winds tend to flow around the major obstructions, speeds increase with height, increase toward mid-afternoon, flow up slopes when heated, and down when cooled. Only the few right angle turns violate the minimum amazement principle. On the other hand, they occur generally in very light wind areas. No doubt some of this can be reduced by adjustment of some of the many input parameters such as influence distance for observed winds, or the convergence criteria for the divergence minimization procedure, etc. Another interesting feature shown is the very light wind regime over the main downtown area of the dual metro area centers. This may just be a manifestation of the pooling effect of collecting, cool drainage flow. A complete collection of computed results for the selected test day is given in Appendix A.

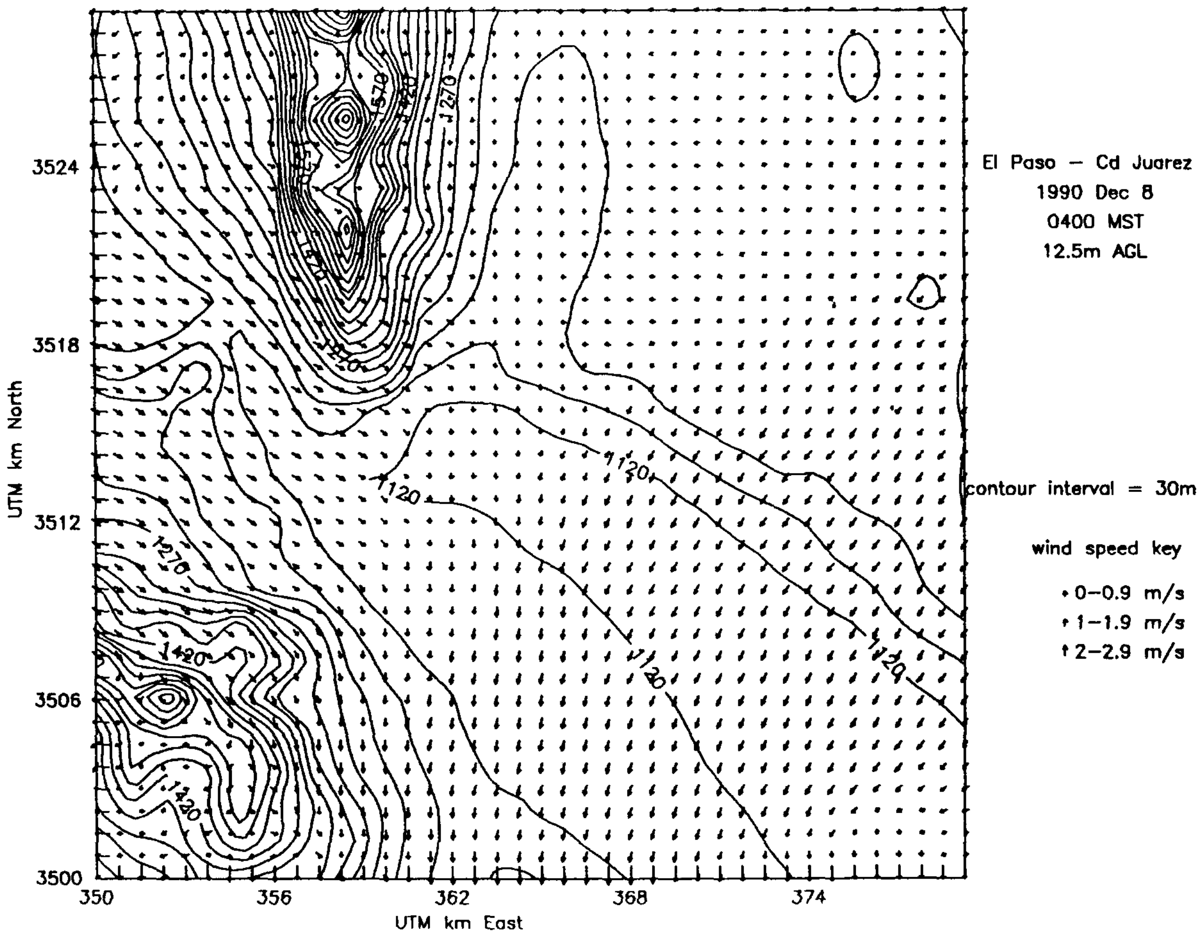


Figure 32 Early morning (0400 hours) ground-level (13 m agl) wind fields predicted by the Diagnostic Wind Field model on December 8.

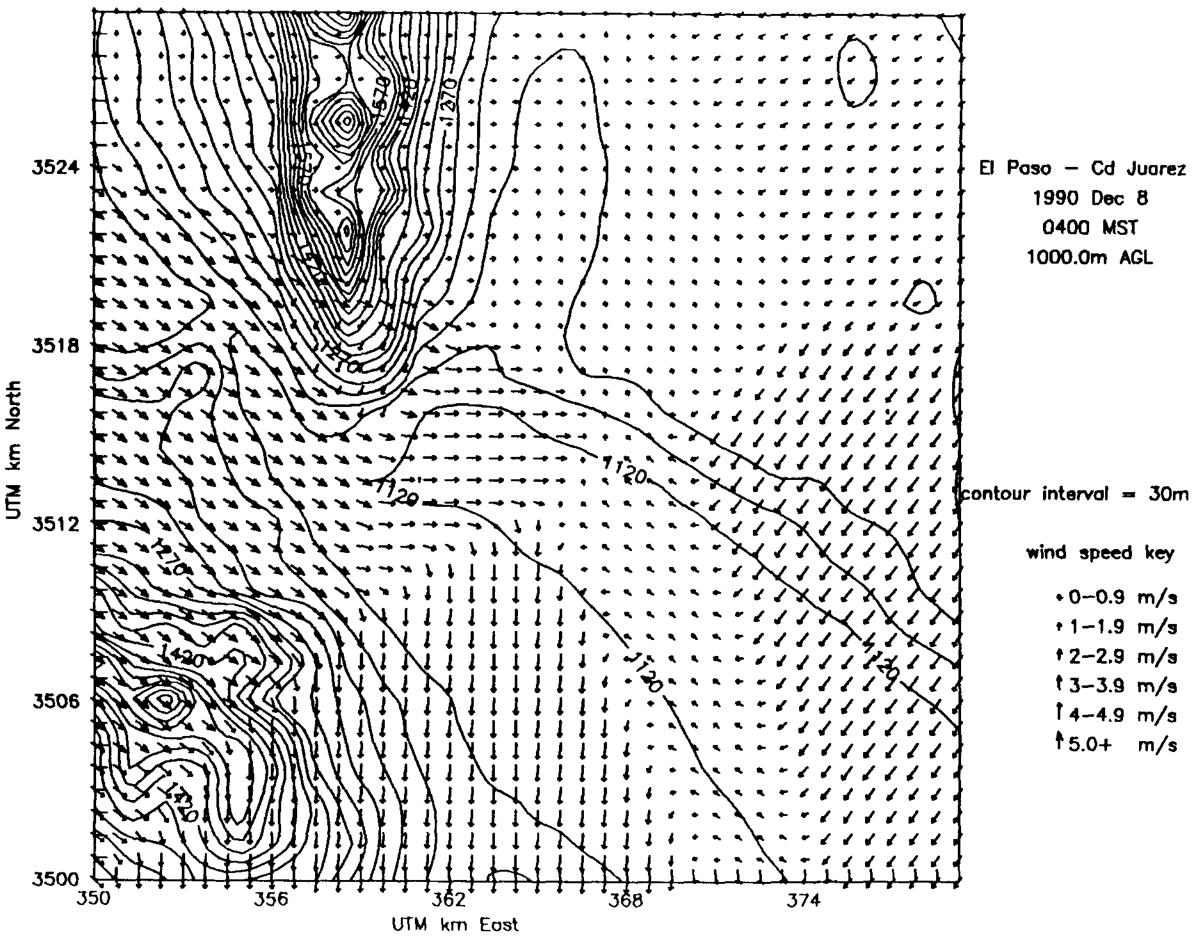


Figure 33 Early morning (0400 hours) upper-level (1000 m agl) wind field predicted by the Diagnostic Wind Field model for December 8.

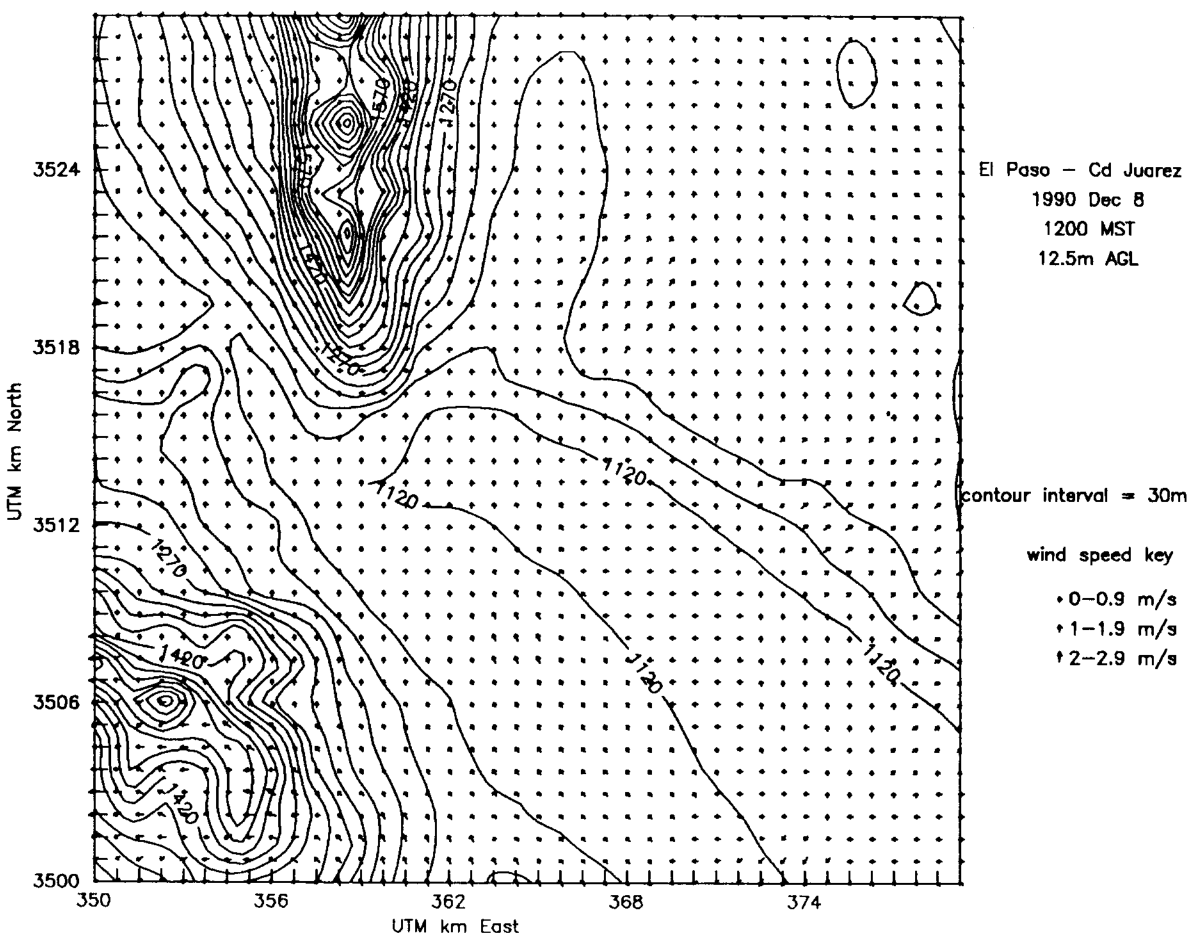


Figure 34 Midday (1200 hours) ground-level (13 m agl) wind field predicted by the Diagnostic Wind Field model for December 8.

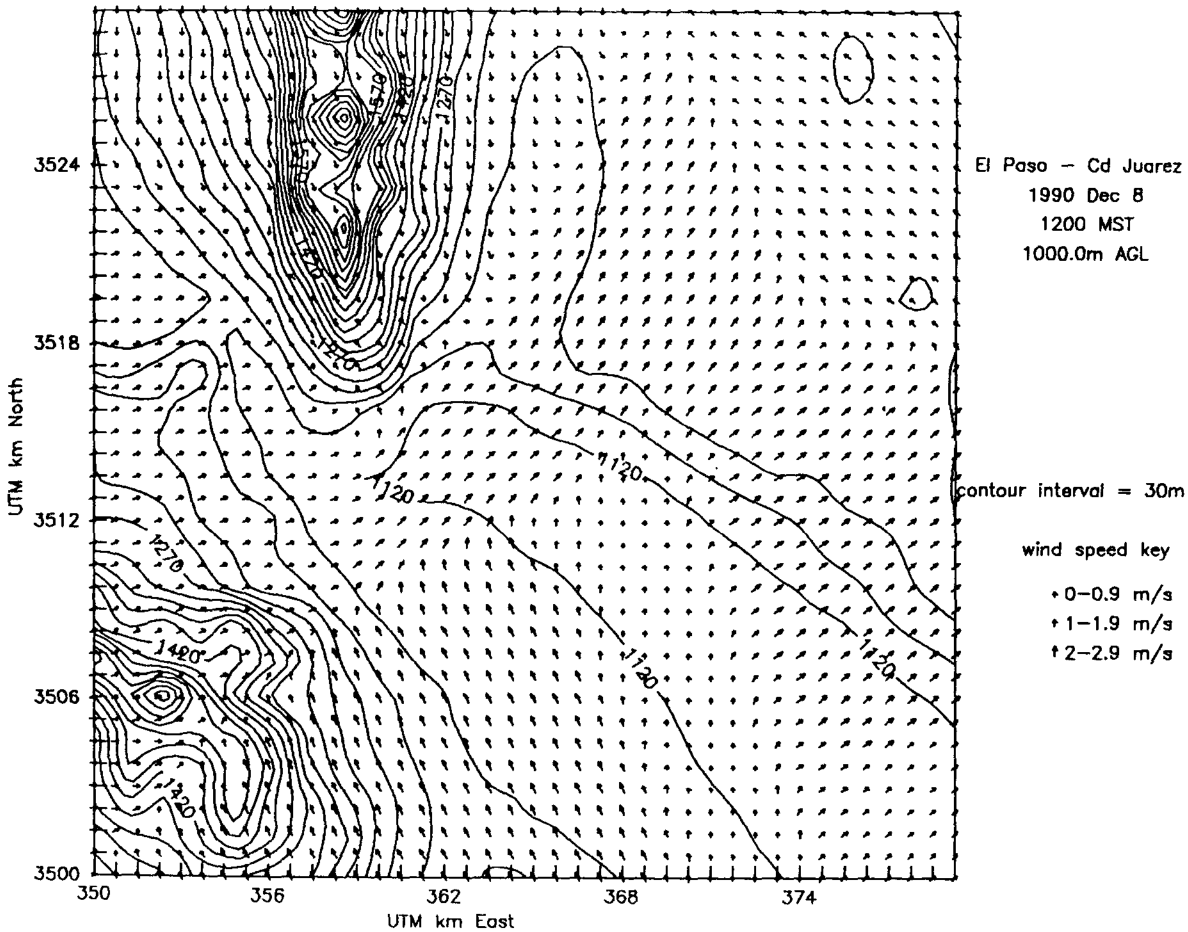


Figure 35 Midday (1200 hours) upper-level (1000 m agl) wind field predicted by the Diagnostic Wind Field model for December 8.

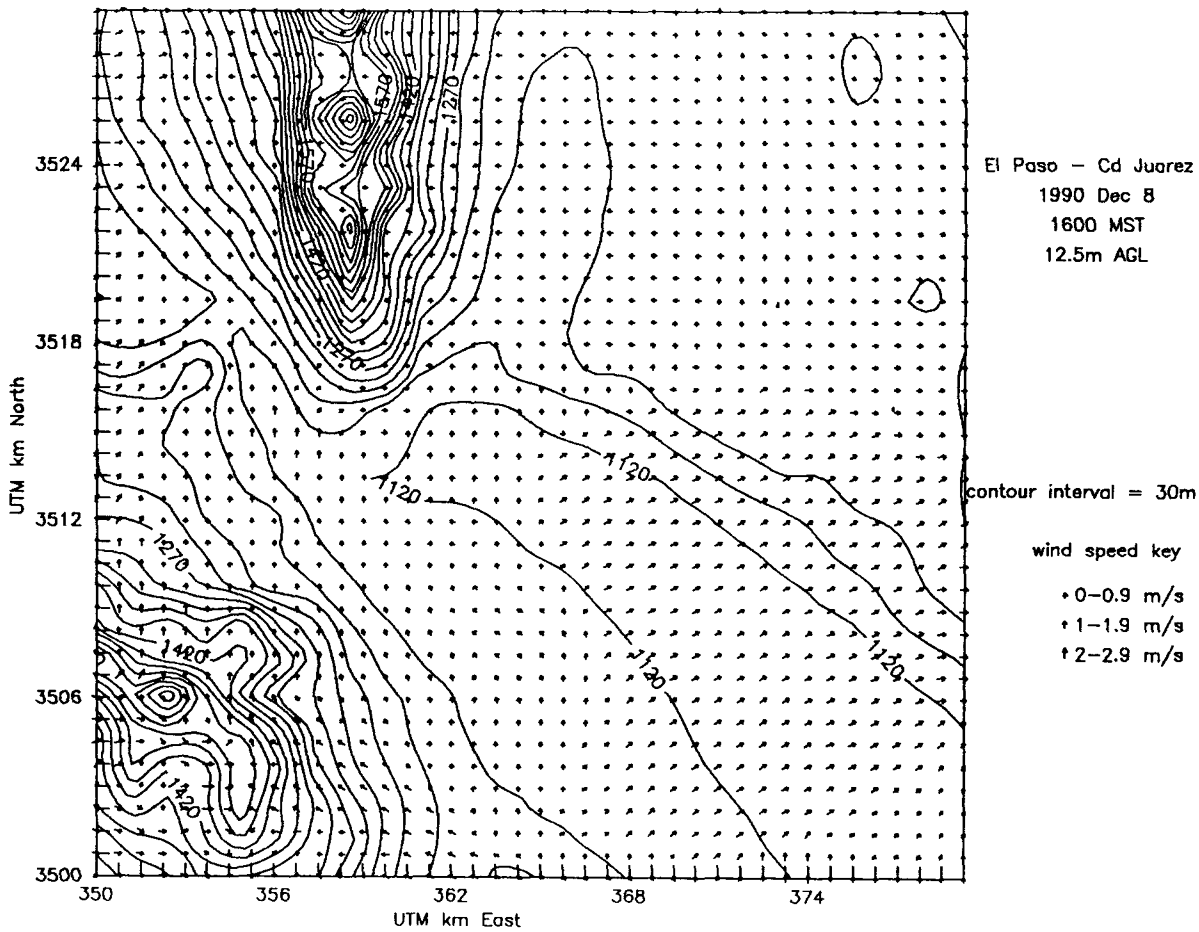


Figure 36 Afternoon (1600 hours) ground-level (13 m agl) wind field predicted by the Diagnostic Wind Field model for December 8.

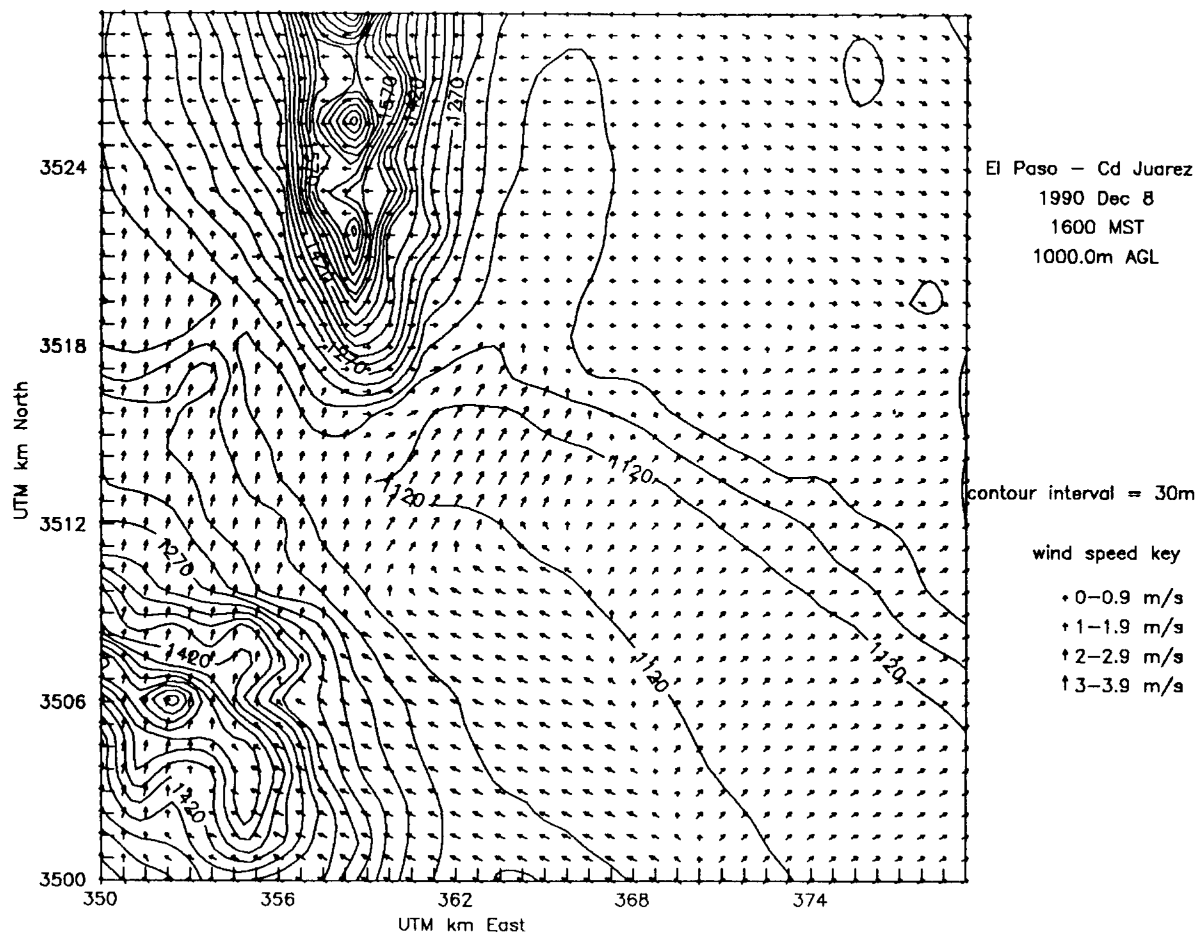


Figure 37 Afternoon (1600 hours) upper-level (1000 m agl) wind field predicted by the Diagnostic Wind Field model for December 8.

5.4.3 Summary of FPM, CPM and PM_{10} Measurements

5.4.3.1 PM_{10} composition and correlation analysis

Aerosol mass concentration measurements are summarized for all sites in Table 12. The highest aerosol concentrations in all categories were observed in Cd. Juarez at the Advance Transformer site. A close examination of the data reveals that the highest measurements in both the US and Mexico were encountered in the evening hours. Based on pooled measurements from all sites, the mass fraction of PM_{10} that was attributed to FPM was about 0.33 for El Paso sites and 0.43 for the two Juarez sites.

Graphs showing 12-hour average FPM and CPM in a stacked bar format are given for the five sites equipped with dichotomous samplers in Figures 38 through 42. In general, the CPM levels constitute the majority of the total mass and, as noted earlier, the highest levels are observed in the evening periods. Data from all five sites reveal the same patterns of pollutant concentration over the two week study interval. Particulate mass concentration levels were observed to rise to a maximum during a three-day stagnation period that occurred from December 7 to 10. Levels dropped considerably as the surface winds increased on the morning of December 11. Another increase was observed on the evening of December 15 followed by several days of high surface winds which again decreased aerosol mass concentrations in the area. Another brief increase of pollutants was observed on December 19 and 20 just prior to study completion. The highest levels were observed at the Advance Transformer site followed by the Sun Metro site. Sites showing intermediate particulate mass concentration levels were the Tecnologico site in Juarez and the CAMS-6 site in El Paso. Somewhat surprisingly, the Chamizal site showed the lowest overall levels despite its location on the valley bottom astride the US-Mexico border.

Table 12
Summary of 12-hr FPM, CPM and PM_{10} Measurements

Parameter	N	Mean µg m^{-3}	Minimum µg m^{-3}	Maximum µg m^{-3}
FPM All Sites	183	32	0	229
FPM El Paso	111	23	0	155
FPM Cd. Juarez	72	45	0	229
CPM All Sites	183	52	0	392
CPM El Paso	111	45	0	318
CPM Cd. Juarez	72	63	0	392
PM_{10} All Sites	185	83	0	621
PM_{10} El Paso	111	68	0	473
PM_{10} Cd. Juarez	74	106	0	621

Note: FPM = Particles <2.5 micrometer; CPM = Particles >2.5 and <10 micrometer; PM_{10} = FPM + CPM

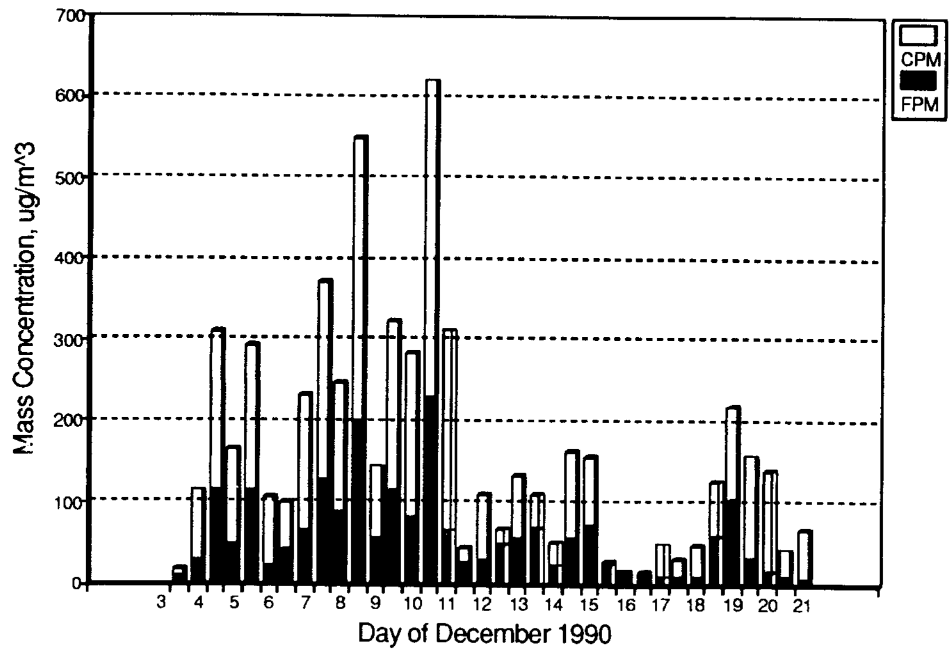


Figure 38 A stacked barplot showing FPM and CPM for all sampling periods at the Advance Transformer site.

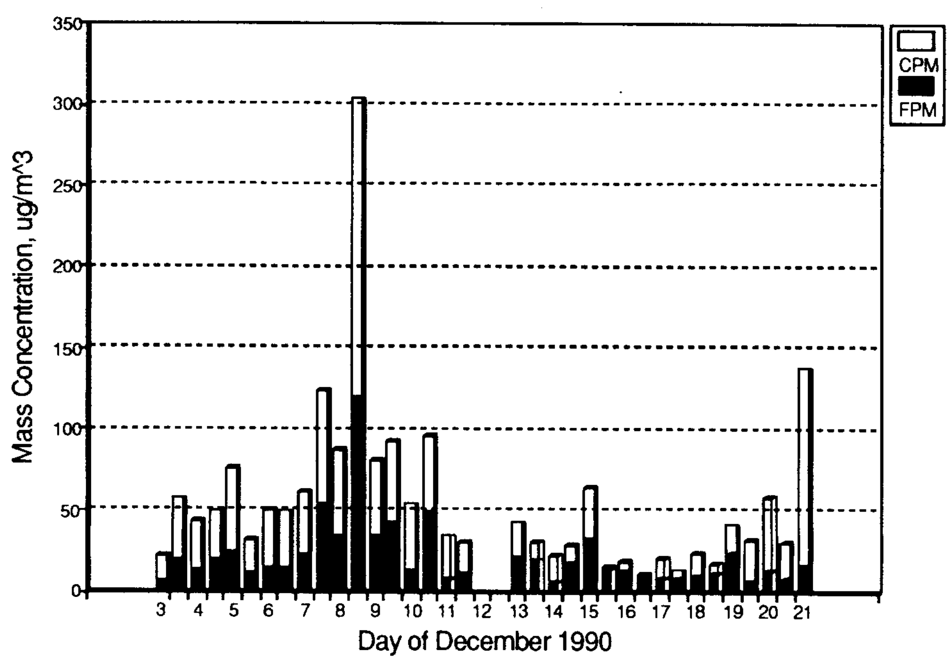


Figure 39 A stacked barplot showing FPM and CPM for all sampling periods at the CAMS6 site [note scale change].

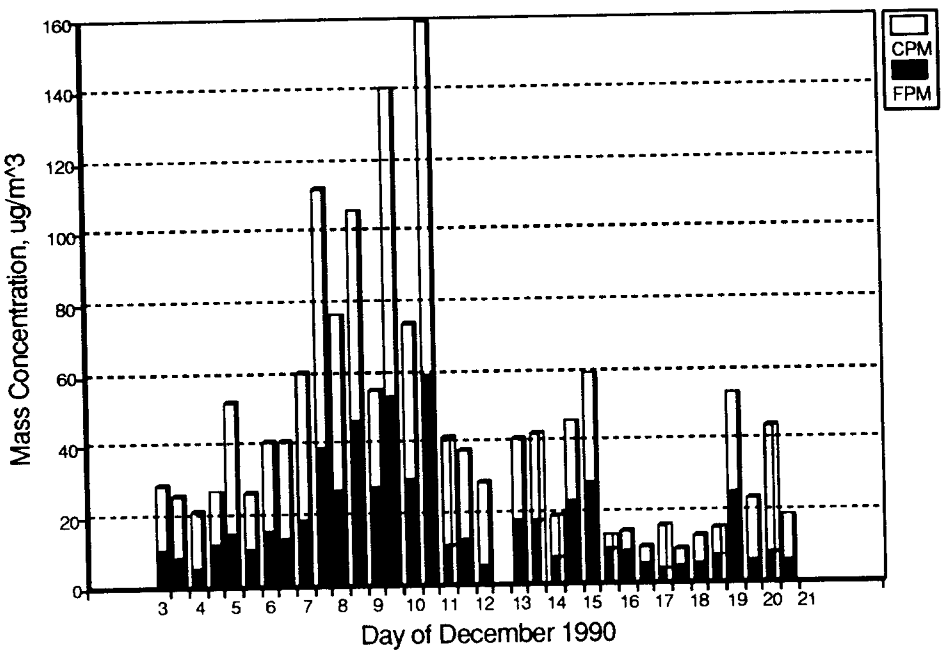


Figure 40 A stacked bar plot showing FPM and CPM for all sampling periods at the Chamizal site.

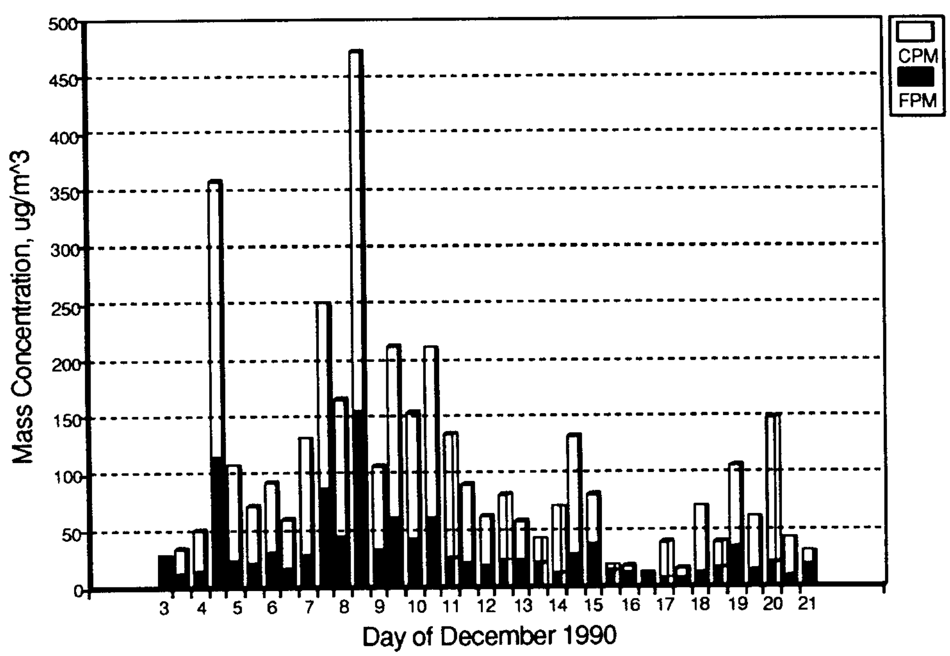


Figure 41 A stacked barplot showing FPM and CPM for all sampling periods at the Sun Metro site [note scale change].

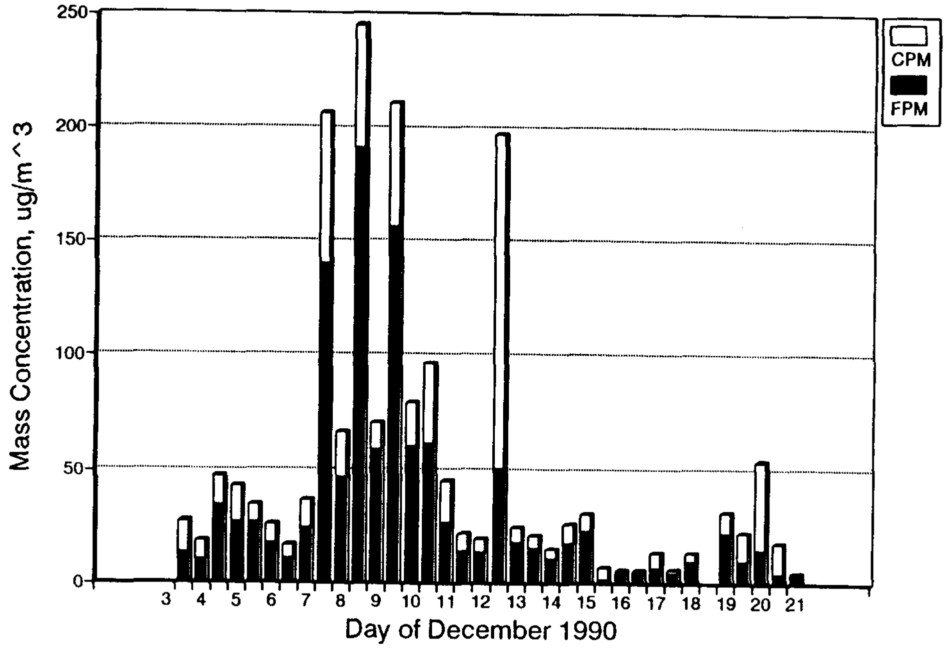


Figure 42 A stacked barplot showing FPM and CPM for all sampling periods at the Tecnologico site.

The results of a correlation analysis among FPM, CPM and PM_{10} are given in Figures 43-45 for 12-hour average data pooled from all five of the special study sites. In general, the plots show that both FPM and CPM correlate well with PM_{10}. This correlation is in large part influenced by the so-called meteorological factor. This factor is related to the atmospheric mixing volume which, in turn, is influenced by the vertical mixing height and local wind speeds encountered during any particular time period. When atmospheric vertical mixing is limited and wind speeds are low, all pollutants, regardless of their source will show concentration increases in the mixed layer. Conversely, when the mixed layer is deep and wind speeds are high, the same pollutants sources will mix into a larger volume resulting in lower ambient concentrations.

The correlation analysis of FPM with PM_{10} from all sites produced a correlation coefficient of 0.91 and a multiplier of about 2.4. That is to say, the PM_{10} mass concentration was a factor of about 2.4 that of FPM measured at the same site during the same 12-hour interval. The correlation of CPM with PM_{10} produced an even higher correlation coefficient of 0.97 with a CPM to PM_{10} multiplier of about 1.4. Correlation analysis reveals that at least during the winter season, FPM is a reasonably good predictor of PM_{10} levels in the region. Furthermore, these preliminary analyses results suggest that combustion sources, a broad source category for FPM, account for 30 to 40% of the measured PM_{10}. The remaining 60-70% of the PM_{10} mass originates from CPM which is derived primarily from crustal sources. CPM, to a large extent, originates from particles produced by mechanical processes such as wind blown soil or re-suspended soil particles from vehicular activity.

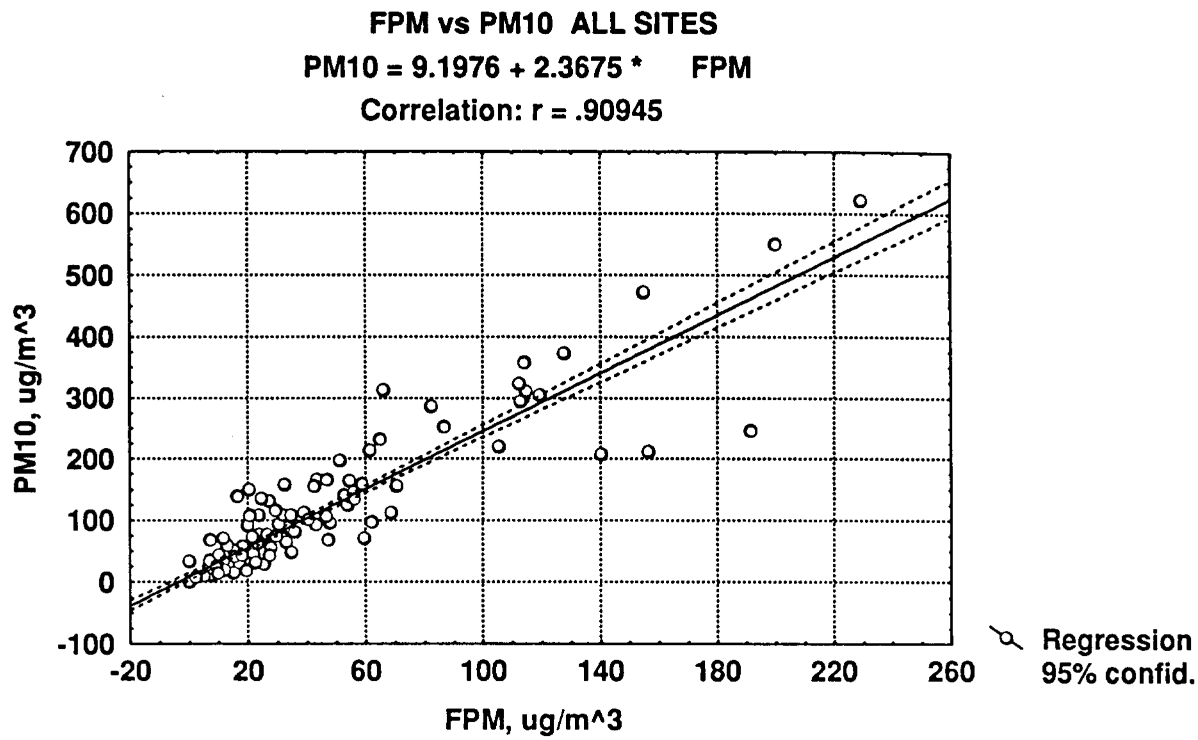


Figure 43 A scatterplot of FPM and PM-10 for all sampling sites and periods.

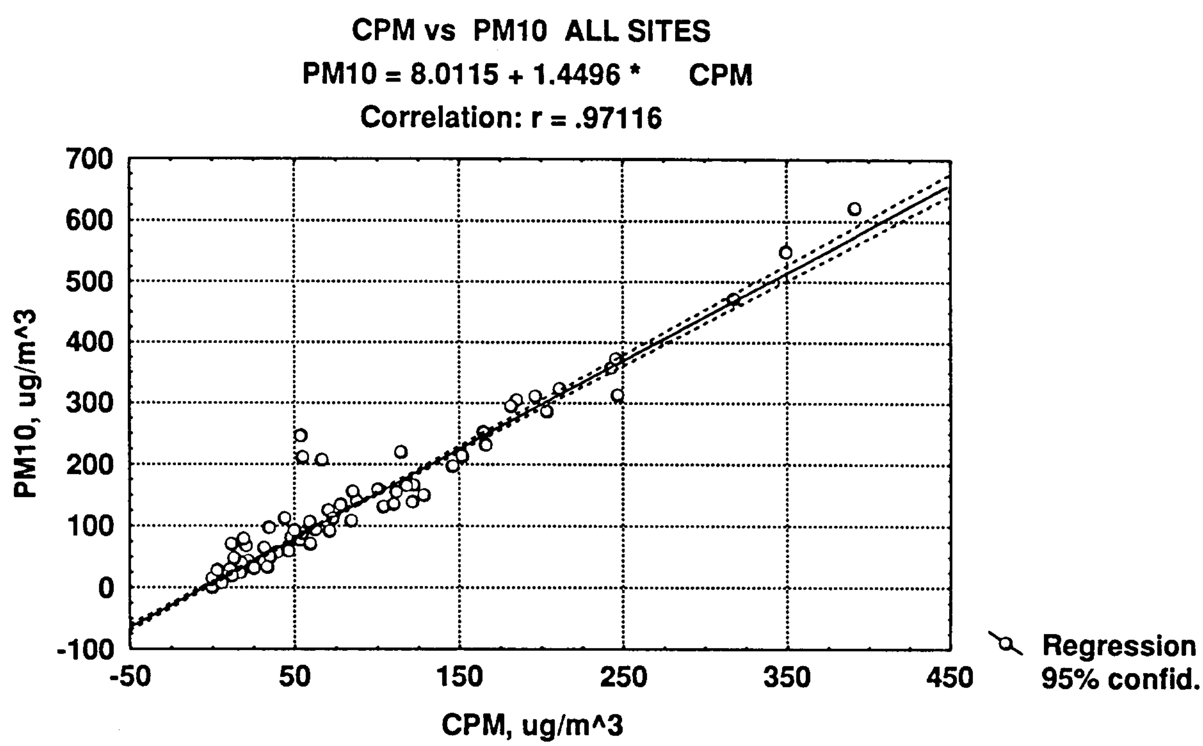


Figure 44 A scatterplot of CPM and PM-10 for all sampling sites and periods.

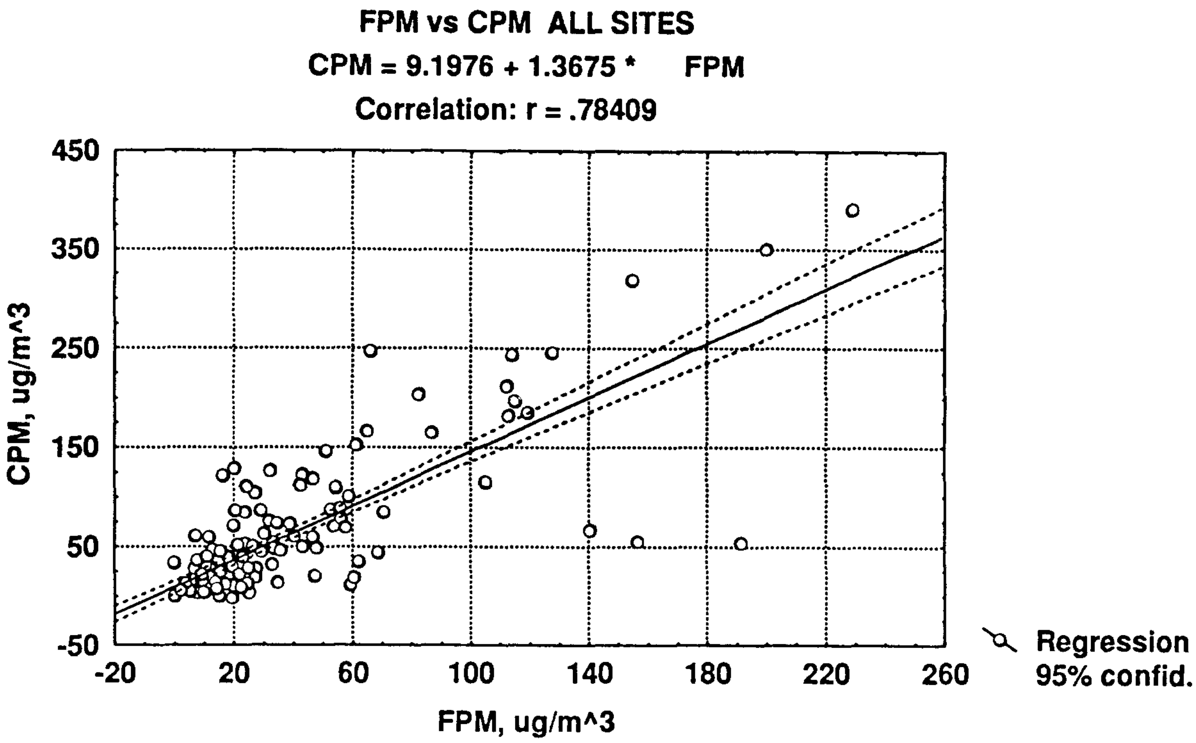


Figure 45 A scatterplot of FPM and CPM for all sampling sites and periods.

5.4.3.2 Additional TNRCC Observations on Aerosol Mass Measurements

TNRCC analysts found that night period concentrations were typically higher and had wider ranges than day concentrations [Dattner, 1993]. Two stagnation episodes marked by elevated pollution levels were observed during the study interval. One of brief duration occurred on Dec 4 followed by a second extended period from December 7 to 10. Not surprisingly, meteorological conditions measured during these stagnation periods revealed low wind speeds and conditions conducive to the formation of nighttime temperature inversions. Synoptic scale weather maps, corresponding to the same December 7-10 time frame, revealed a high pressure ridge to the north of the El Paso-Cd. Juarez area, clear skies and low wind speeds aloft. The highest PM_{10} levels during the study interval occurred on the evening of December 10 when vertical mixing in the atmosphere was suppressed by a temperature inversion.

The authors of the TNRCC report discuss the presence of outliers in plots of fine and coarse mass concentrations from various measurement sites and suggest that further investigation into the observed outliers may yield information about sources and sites.

The results of a correlation analysis between sites is also discussed in the TNRCC report. The observation is made that the lowest correlation is noted for CPM inter-site comparisons. A suggestion is offered that CPM is more localized and less likely to be transported and mixed over the entire airshed by virtue of its relatively short atmospheric residence time. FPM, on the other hand, shows the highest correlation presumably a result of its longer residence time in the mixed layer.

The 12-hour dichotomous sampler measurements were combined into 24-hour averages to estimate the number of PM_{10} NAAQS exceedences likely to have occurred during the study. The results are summarized in Table 13. showing exceedences at all sites except Chamizal. The Advance Transformer site tops the list with eight exceedences.

Table 13
Estimated Number of Exceedences of the US PM_{10} Standard
Based on a Combination of 12-hour Dichotomous Sampler Results

Site	No. of Violations	Min, Max ($\mu g/m^3$)
ADV - Advanced Transformer	8	179, 453
SUN - Sun Metro	5	161, 319
CAM - CAMS6	1	196
TEC - Tecnologico	1	156
CHA - Chamizal Park	0	

from [Dattner, 1993]

5.4.3.3 Spatial Distribution of PM_{10}

TNRCC analysts merged data from sites where 24-hour PM_{10} samples were collected with the five special sites equipped with dichotomous samplers and 12-hour sampling intervals in order to conduct a spatial analysis. Data from a total of fifteen sites were used with a data interpolation and plotting package to produce contour plots for 24-hour sampling periods on December 7, 13 and 19. Figures 46 - 48 illustrate the results of this particular analysis. A weighted average was used to estimate a midnight to midnight 24-hour average from the dichot samplers which were started and stopped at 5AM and 5PM. The contour plots, in general reveal a gradient of increasing PM_{10} as one moves in a southerly direction toward the Cd. Juarez sites. The contour plots look similar to those produced during the 1989 saturation PM_{10} study discussed in an earlier section of this report (Figure 9). The Advance Transformer site appears to be a so-called "hot spot" with measured levels of aerosol mass usually well in excess of levels observed at the other sites. TNRCC researchers speculate that local brick kilns produced thick black smoke which may have significantly impacted the samplers at this site. A moderate particulate concentrations gradient from high to low is also observed in the eastern portion of the basin between Cd. Juarez and eastern El Paso.

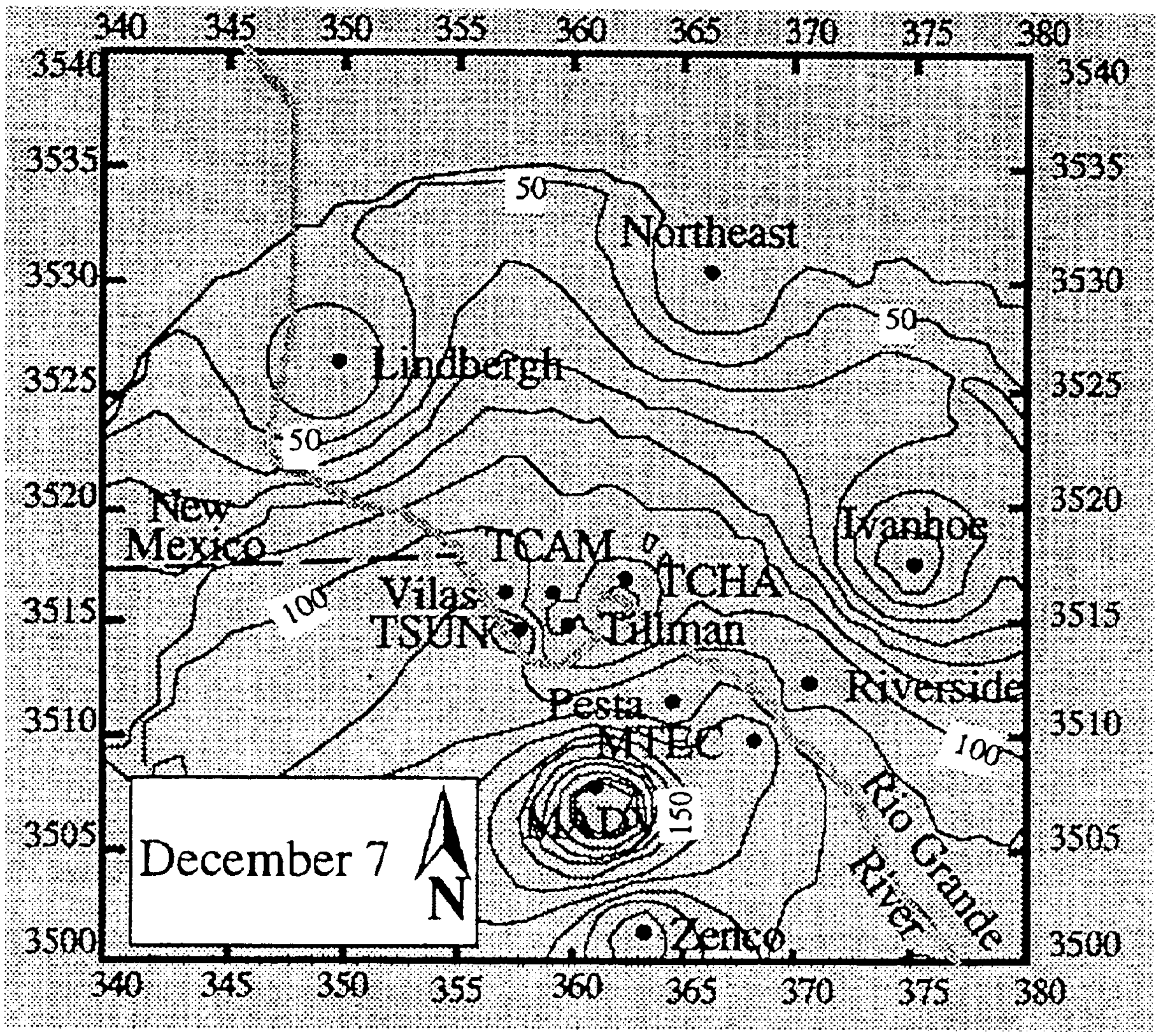


Figure 46 A contour plot of PM-10 levels interpolated from measurements at 15 sites on December 7 [from Dattner, 1993].

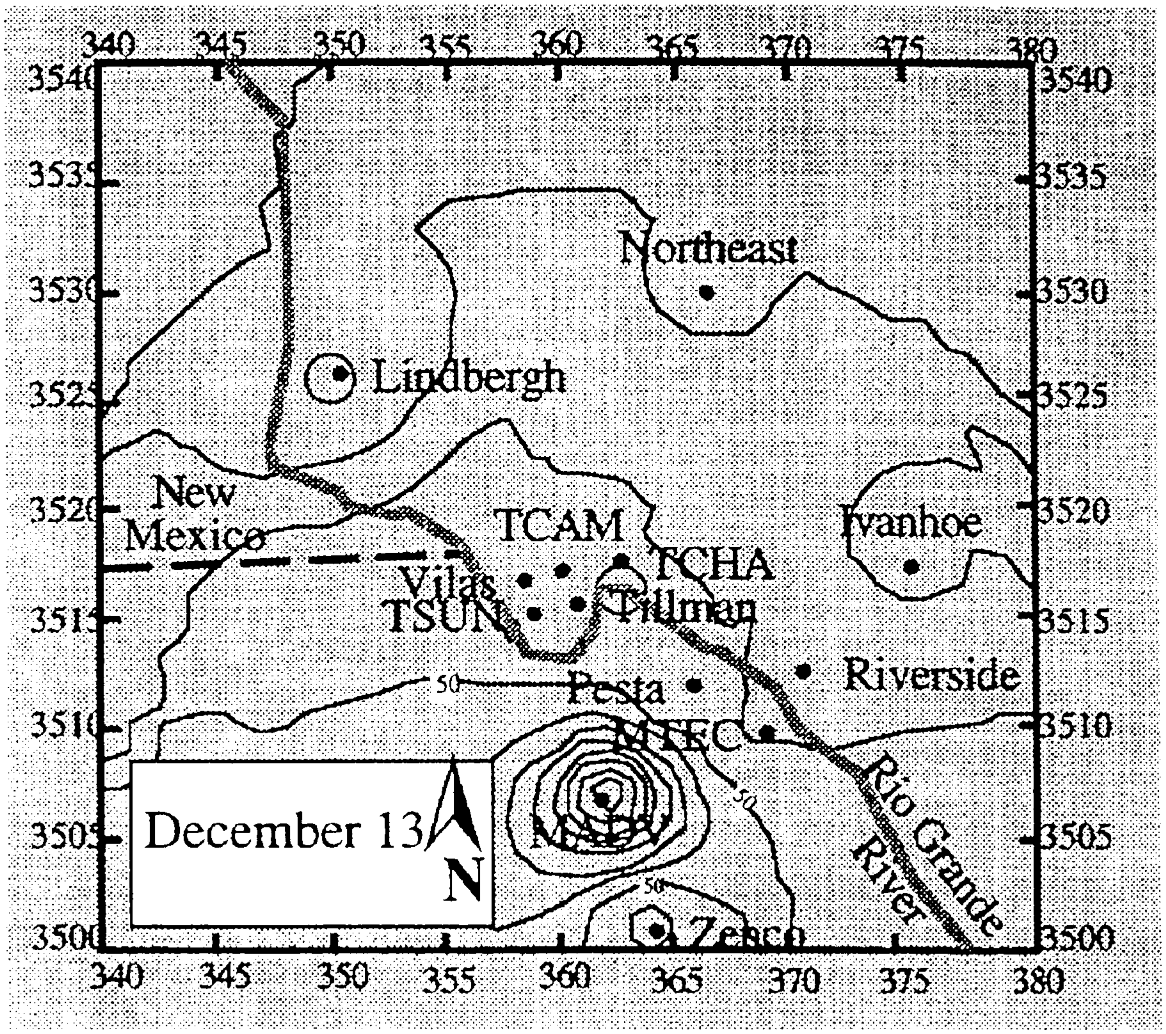


Figure 47 A contour plot showing PM-10 levels interpolated from measurements at 15 sites on December 13 [from Dattner, 1993].

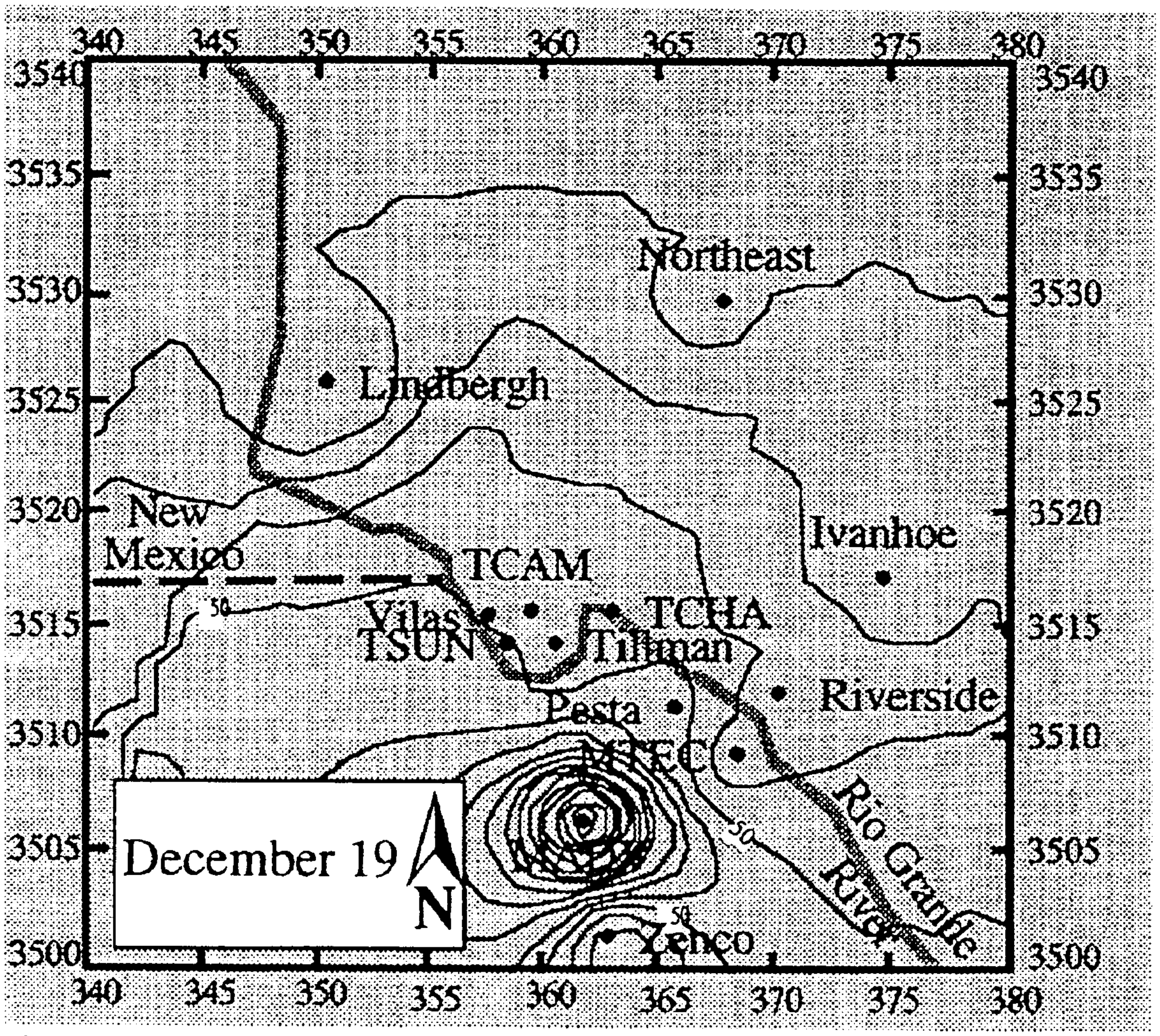


Figure 48 A contour plot showing PM-10 levels interpolated from measurements at 15 sites on December 19 [from Dattner, 1993].

5.4.3.4 Conclusions from Particulate Mass Concentration Analysis

The following conclusions are drawn from both TNRCC and SNL analyses of the mass concentration data collected during the short-term study.

Considerable variation was observed in the PM_{10}, CPM and FPM measurements made at the various monitoring sites in the study. Concentration levels were clearly the highest at the Advance Transformer site in southwestern Cd. Juarez and may have been heavily influenced by local combustion sources such as brick kilns. The lowest mass measurements were observed at the Chamizal site which was located more or less at the geographic center of the valley.

By combining the 12-hour mass concentration measurements, exceedences of the US PM_{10} standard level were estimated to have occurred at all sites except the Chamizal site during the study interval.

Night period measurements of particulate mass were typically higher than day period measurements at all sites, presumably a result of diminished vertical mixing of the atmosphere during the evening and early morning hours. Considerable altitude effects were observed as well, with low-lying sites showing much higher levels than adjacent sites several hundred feet higher.

On average, the FPM was 30 to 40% of the PM_{10}. Both FPM and CPM correlated with PM_{10} reasonably well, suggesting that either could be a reliable predictor of PM_{10}.

Spatial analysis of the particle concentration data suggest a concentration gradient highest in Cd. Juarez and lowest in El Paso; however, the relatively small number of sampling sites in Cd. Juarez limits the significance of this observation.

5.4.4 Elemental Species Measurements

A receptor modeling approach for air pollution source identification hinges upon a detailed understanding of the composition of the particulate sample. A determination of the elemental composition of the sample is one of several aerosol speciation techniques employed in this study. The conventional method for the determination of aerosol elemental composition is through the use of X-ray fluorescence analysis. In this method, the particle-loaded filter is placed in an X-ray spectrometer and bombarded with X-rays. This produces characteristic electronic transitions in the sample elements. The type and intensity of electronic transition is then directly related to a specific element along with its mass loading on the filter. The methodology is non-destructive and relatively cost-effective since a single analysis lasting several minutes gives quantitative measurements for more than 30 elements.

Funding limitations required the selection of a subset of all filters to be analyzed by X-ray fluorescence. Fifty fine filters and 22 coarse filters were selected for analysis. Filters from heavily polluted periods were selected over those from periods with lower particulate mass concentrations. A summary of fine and coarse elemental concentrations from two sites, Advance Transformer and CAMS6 are shown in Tables 14 and 15. The reader is referred to the TNRCC report for a complete description of the elemental analysis [Dattner, 1993]. Significant levels are noted for the crustal elements like calcium, silicon and iron. Chlorine and sulfur are also observed at high levels. Lower, but nonetheless, measurable levels are observed for lead, bromine, arsenic and cadmium.

Table 14
Summary FPM Elemental Analysis Data for a Cd. Juarez and El Paso Monitoring Site

Element	Advance Transformer		CAMS6	
	Average ng/m^3	Std. Dev. ng/m^3	Average ng/m^3	Std. Dev. ng/m^3
FPM	102,100	67,480	39,770	31,434
Al	172	57	71	61
Si	1,101	546	611	378
S	1,514	792	1,266	627
Cl	4,219	3,506	941	1,348
K	608	399	249	198
Ca	2,414	1,459	862	705
Ti	23	14	14	9
V	10	8	10	6
Cr	3	3	7	4
Mn	20	17	19	7
Fe	316	170	285	145
Cu	81	55	114	64
Zn	160	87	180	105
As	51	44	86	67
Se	11	12	11	7
Br	100	53	33	31
Sr	8	4	5	2
Pb	470	232	236	125
Cd	10	5	8	4
Sn	10	8	5	5
Sb	40	37	15	12
Ba	4	7	16	8

Table 15
Summary CPM Elemental Analysis Data for a Cd. Juarez and El Paso Monitoring Site

Element	Advance Transformer		CAMS6	
	Average ng/m^3	Std. Dev. ng/m^3	Average ng/m^3	Std. Dev. ng/m^3
CPM	28,820	22,169	54,950	21,849
Al	498	501	923	292
Si	2,339	1,781	4,166	1,524
S	154	115	279	41
Cl	130	171	117	42
K	342	263	607	228
Ca	3,594	3,106	7,007	3,393
Ti	49	40	99	47
V	4	4	9	2
Cr	4	5	9	1
Mn	15	11	57	4
Fe	607	423	1,521	404
Cu	12	6	137	61
Zn	40	69	71	8
As	2	2	18	1
Se	1	0	3	1
Br	6	5	5	3
Rb	2	1	4	1
Sr	22	15	27	11
Pb	28	21	59	2
Zr	2	2	4	0
Cd	2	1	4	1
Sn	0	1	2	2
Sb	0	1	4	1
Ba	16	17	46	7

5.4.5 Aerosol and Semi-volatile Carbon Measurements

5.4.5.1 Aerosol Carbon

TNRCC analysts extended considerable effort in the analysis of the large collection of fine and coarse fraction quartz filter pairs collected at the five specially equipped study sites. A total of 150 filter pairs were analyzed by conventional staged thermal combustion methods. Using this method, the aerosol carbon is further broken down into such categories as organic and elemental carbon which can provide additional information on source contributions. A number of general conclusions from the TNRCC aerosol carbon analysis are summarized below.

The mass fractions of FPM and CPM that were attributable to particulate carbon are summarized in Table 16 for the five study sites. About 50 to 60% of the FPM is attributable to volatile and non-volatile carbon aerosol. The aerosol carbon mass fraction for the CPM was on the order of 15 to 20% and 10 to 20% of PM_{10}.

Table 16
Summary Aerosol Carbon Mass Fractions by Sampling Site

Site	FPM Carbon Mass Fraction	CPM Carbon Mass Fraction	PM_{10} Carbon Mass Fraction	No. Samples
ADV	0.48 ± 0.16	0.16 ± 0.19	0.27 ± 0.14	29
TEC	0.40 ± 0.12	0.31 ± 0.16	0.36 ± 0.12	25
CAM	0.52 ± 0.13	0.13 ± 0.06	0.28 ± 0.09	27
CHM	0.50 ± 0.13	0.10 ± 0.05	0.23 ± 0.08	21
SUN	0.47 ± 0.16	0.09 ± 0.04	0.20 ± 0.07	34

from [Dattner, 1993]

As normally encountered in urban aerosol, volatile aerosol carbon concentrations were higher than the non-volatile concentrations at all sites, usually by a factor of two or greater. Differences between day and night concentrations were similar to those observed for overall mass concentrations--levels were highest during the evening periods.

The TNRCC conducted a "math spectral analysis" on the aerosol carbon data and reported that 12 distinct spectra were derived from the data set. No implications in terms of source attribution are reported however since the analysis methodology and its physical significance are still under development.

5.4.5.2 Semi-volatile Organic Aerosol

A separate sampler at CAMS6 was deployed to collect the semi-volatile component of the aerosol so that the concentration of individual semi-volatile organic species could be determined. Analysis by GC-MS gave a measure of total polycyclic aromatic hydrocarbons (PAH) as well as selected species, such as benzo(a)pyrene, pyrene and others, some of which are either known or suspect human carcinogens. A series of 12-hour samples were collected over the same time frame as the coarse and fine particulate samples. A graph showing total PAH as well as selected PAH species is shown in Figure 49 showing concentration increases that correlate to increased stagnation around December 7. Not surprisingly, increases in total PAH and individual species correlate with the stagnation periods encountered during the study. Increases during these periods were observed to be as high as 10-fold above the background levels encountered during "clean air" conditions.

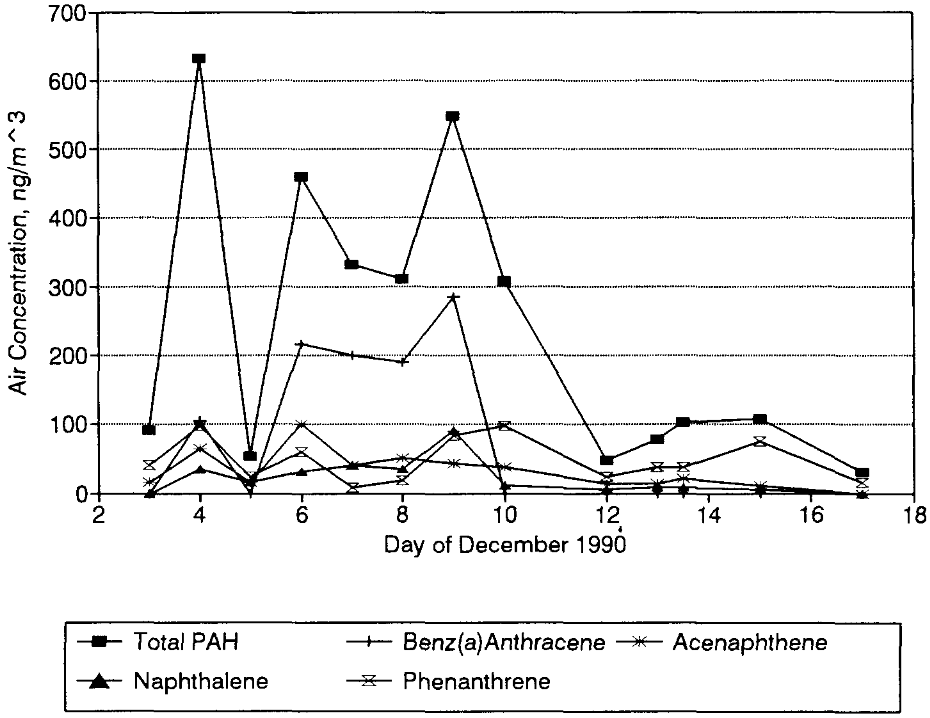


Figure 49 Total polycyclic aromatic hydrocarbon and selected species concentrations measured at the CAMS6 site during a portion of the study interval [from Dattner, 1993].

5.4.6 Other Measurements

5.4.6.1 Annular Denuder Measurements

TNRCC made a limited number of measurements with annular denuders[2] at the CAMS6 site during the study interval. The measurements are deemed relevant since they allow for the speciation of inorganic acid gases and aerosols, such as sulfur dioxide, aerosol sulfate, nitric acid and aerosol nitrate. Measurements of these particular species allow inferences to be drawn concerning the extent to which secondary aerosol is a factor in the winter season. Secondary aerosol is particulate matter that is formed by reaction of various gaseous pollutants, such as sulfur dioxide or nitric acid, with other atmospheric constituents. Knowing these species' relative concentration levels can also give an indication as to the relative "age" of the aerosol in the region;

[2] Annular denuder sampling technology allows differentiation and quantitation of related gas and particle species such as sulfur dioxide and aerosol sulfate from the same sampled volume of air.

information which may be further used to infer whether the gaseous sources such as sulfur dioxide are local or whether they are regional and transported into the local area by wind flow.

Results from TNRCC analysis of particulate and gaseous sulfur and nitrogen species reveal that the dominant sources in this category are local. A ratio of gaseous to particulate sulfur of about 0.9 is reported which indicates a relatively "new" source of sulfur gas. Gaseous sulfur sources transported into the region from distant sources would show a much lower ratio since much of the gas would be converted to the particulate sulfur phase during the transport process. This finding is corroborated with other sulfur aerosol measurements suggesting local sources and is consistent with the presence of the local ASARCO copper smelting operation from which gaseous sulfur emissions are known to occur.

A lower gas to particle ratio of about 0.7 was observed for nitrogen species. TNRCC analysts suggest that this ratio may reflect faster gas to particle reaction rates for the nitrogen species when compared to the sulfur species or the fact that higher levels of particulate nitrogen are released from primary sources. The TNRCC analysts also point out that the gaseous nitrogen emissions are primarily from ground level vehicular sources as compared to gaseous sulfur emissions that are released from elevated smelter stacks. Ground level emissions are thus released into the mixed layer which results in longer residence time as compared to gaseous sulfur emissions aloft which are only periodically mixed into the inversion layer during the late afternoon when the mixed layer approaches the stack height.

Measurements of sulfur dioxide by annular denuder over an approximate two-week interval reveal higher daytime levels than nighttime levels. The largest daytime 12-hour average observed was about 190 $\mu g/m^3$. The higher daytime values are taken to confirm relatively shallow mixed layer that exists during the evening hours. During these times the sulfur gas emissions occur above the mixed layer and are not effectively transported down to ground level.

Smaller differences are observed between nighttime and daytime gaseous nitrogen species such as nitric acid and nitrous acid. This observation suggests that sources of gaseous nitrogen species are primarily vehicular in nature and by virtue of their ground location are always in the mixed layer. Thus, day-night differences are minimized for the nitrogen species.

5.4.6.2 Electron microscopy analysis

The TNRCC collected fine and coarse aerosol fractions on a specialized dichotomous sampler designed to optimize particle loadings on the filter for microscopy analysis. The intent of this effort was to combine receptor modeling approaches with information on the elemental composition of discrete particles via electron microscopy in much the same way as done in the earlier Energy Technologies study discussed earlier in this report. Samples were collected at the CAMS6 station and sent to the EPA-AREAL laboratory for analysis. The filters were determined to be overloaded with particles such that the analysis could not be completed.

5.4.7 Temporal PM_{10}, Nephelometer and CO data analysis

The TNRCC conducted an analysis of continuously monitored PM_{10}, CO and nephelometer data collected at the Chamizal site during the December 7-10 stagnation event which revealed some interesting patterns and relations among these pollutants. A plot of these three parameters is given in Figure 50 showing a high degree of correlation among the three parameters. A number of conclusions drawn by TNRCC analysts from this analysis are summarized below.

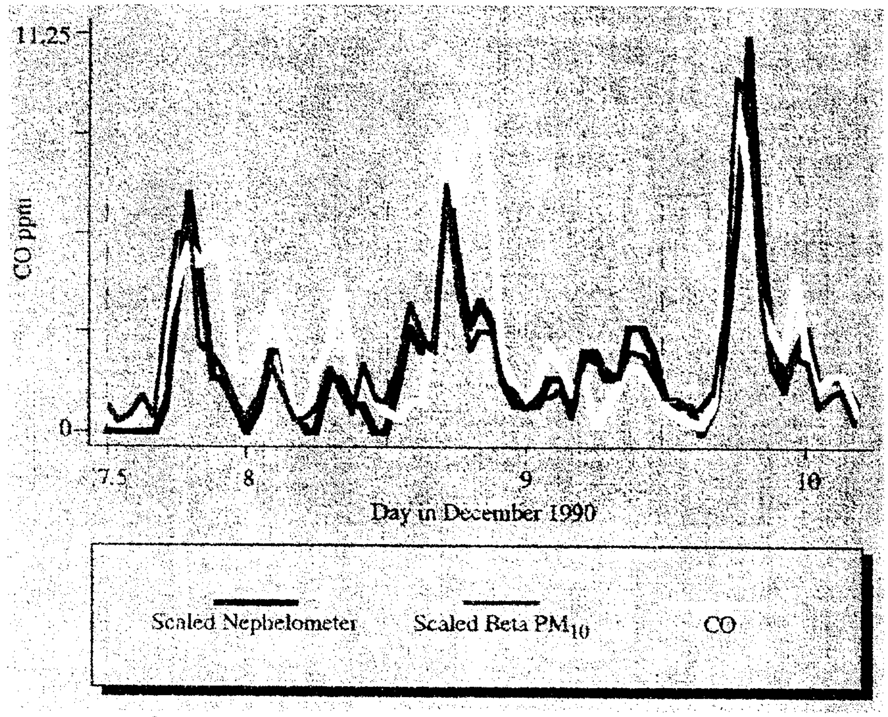


Figure 50 A graph of aerosol light scattering, CO and PM-10 measurements from the continuous monitors at the Chamizal monitoring site [from Dattner, 1993].

The high degree of correlation over reasonably short time scales (1-hour) suggests a common source type for these three measured parameters.

The three parameters show peaks during the morning and evening commute periods suggesting that vehicular activity may be the predominate source of these parameters.

Carbon monoxide is commonly associated with combustion sources and with vehicular sources in particular. Biomass burning also produces CO however the degree to which this source is a major contributor in the El Paso-Cd. Juarez region is unclear from these data.

Late evening CO peaks are not as well correlated with nephelometer and PM_{10} peaks suggesting the presence of biomass combustion sources not in the vehicular category.

The high degree of PM_{10} correlation with CO suggests the presence of two possible PM_{10} sources related to vehicular sources, namely: tailpipe emissions and entrained road dust associated with vehicular travel. One or both of these source categories are responsible for the observed PM_{10} levels.

A TNRCC comparison of nephelometer data from the Chamizal and the CAMS-6 sites over the same measurement interval reveals an appreciable degree of correlation, however, not as high as that observed between the three parameters at the Chamizal site discussed previously. This comparison is taken to suggest that pollutant measurements at a particular site reflect, to a significant extent, the presence of sources local to that particular site. In general, the results of these analyses illustrate the effectiveness of using time-resolved measurements to help clarify source contributions in the area.

5.4.8 Receptor Modeling Analysis

5.4.8.1 Approach and Factor Analysis Method Description

One particular aspect of the short term winter-season study involved a preliminary evaluation of receptor modeling techniques as applied to the data set produced during this two week intensive study interval. Receptor modeling approaches are viewed as one of the ways that predictions concerning current and future pollutant levels can be made by the State of Texas in their development of a PM_{10} State Implementation Plan for the El Paso-Cd. Juarez region. The other traditional approach used in SIP analyses for various regulated pollutants is the combination of emission inventories with air dispersion modeling. This approach relies heavily on the preparation of a pollutant emission database which incorporates source estimates for all significant sources in a particular region. These include area, point, vehicular or mobile sources and other categories as well. These emissions data are combined with hourly measurements of meteorological parameters made at selected locations in the area of interest, including such measurements as wind direction, wind speed, atmospheric mixing height and atmospheric turbulence. The meteorological parameters are used to predict the transport and diffusion of pollutants from the numerous sources and ultimately, to estimate pollutant concentrations at selected receptor sites of interest. The discussion of the SAI report in Section 3 gives a brief review of some of the dispersion models available for these types of analyses.

Receptor modeling techniques, on the other hand, differ from dispersion modeling techniques in that a detailed pollutant data set is collected at a specific receptor site or sites in discrete sampling intervals. Analysis of the collected aerosol provides detailed composition of the sample including the elemental and carbon species composition. The elemental composition of the sample is then used to draw inferences about various local and regional sources and their relative degree of contribution to measured mass categories such as FPM or PM_{10}. For example, the extent to which sulfur containing aerosols are present in a sample may be directly related to the amount of sulfur gas emitted from a local copper smelter; or, the extent to which silicon particles are observed in a sample may be used to estimate the extent to which soil sources such as wind-lofted dust or dust re-suspended by vehicles from unpaved roadways are present in the sample. One of the most powerful receptor models available for source strength determination is the EPA Chemical Mass Balance or CMB model. This model takes the elemental signatures of multiple sources and by classical least squares fitting techniques determines the extent of each source contribution to a measured sample. This approach has merit; however, a limitation to successful application of this model is a requirement for measurements of the elemental composition of the major sources of interest in the region--a requirement which can result in costly collection and analysis of numerous source samples. Alternatively, literature values of various source categories can be used. In many cases, however, these may be of insufficient detail or specificity for a particular industrial process or area.

A related receptor modeling technique employs the use of factor analysis techniques which allow classification of the numerous variables in a data set from a receptor site or sites into groupings of variables that may be logically related to actual source categories. In general factor analysis and its companion approach principal component analysis are statistical approaches used to: (1) simplify a data set composed of many variables into a fewer number of variables or factors (principal components analysis); or, (2) to discover underlying structure in a data set composed of many variables (factor analysis). In either case, the methods attempt to extract so-called factors from the data set in such a way that the factors account for as much of the variability in the original data set as possible. Factor analysis has often been applied to the data sets obtained from air sampling as a receptor modeling tool. Particulate matter that has been analyzed for elemental composition yields a data set that has many variables well suited for this approach.

Since many sources emit distinctive or unique elements, a factor analysis treatment of the data can often help elucidate sources in a particular region.

Factor analysis is a desirable approach since it allows the data set to reveal source categories with a minimum of analyst bias or intervention. Correlations among variables are mathematically determined with limited analyst intervention. The CMB approach on the other hand requires the analyst to select appropriate source categories for least squares fitting routines and source strength determination. It is often desirable to use factor analysis as a first step in exploring potential sources, with a follow-on analysis using the CMB model after significant sources have been identified in the data set.

5.4.8.2 Factor Analysis Results

Factor analysis was carried out on the combined data set and subsets that were assembled from all five special study sites by Sandia National Labs researchers using factor analysis routines in the Statistica® (Statsoft® Inc, Tulsa, OK) software package. A detailed description of the underlying theory and approaches to factor analysis is beyond the scope of this report, however many references are available that describe this approach in more detail [Hopke, 1985; Stevens, 1986; Harman, 1967].

Factor Analysis on the FPM Data Set

Factor analysis was carried out on a raw and normalized FPM elements data set which included the suite of elements analyzed by XRF along with the measured fine particle mass concentration for each filter. Earlier work has shown that normalization of, all variables in the data set to a parameter such as FPM helps to reduce co-linearity of all variables caused by the meteorological factor. Variable co-linearity can weaken the ability of factor analysis to detect the underlying structure in the data set since all variables tend to extract under a single meteorological factor. In this case all 12-hour average fine fraction element concentrations were divided by the 12-hour average FPM, and coarse fraction element concentrations by the 12-hour average CPM. The degree to which the extracted factors explain the variability encountered in the FPM data set is given in Table 17. The results reveal only a moderately successful model with about 58 percent of the variance explained by the five factors that were extracted.

Table 17
Goodness of Fit Results for a 5-Factor Solution to the Normalized FPM Data Set

Factor	Total Variance %	Cumulative Variance %
1	24.5	24.5
2	16.8	41.4
3	7.2	48.5
4	5.3	53.8
5	4.0	57.8

The loadings of the elemental variables on the five factors after a varimax[3] rotation are given in Table 18. For clarity, those elements with loadings in excess of 0.5 are shaded. Several source patterns can be identified in the data set. The first factor shows high loadings for Cu, Zn, As, and Pb. Clearly, this factor is indicative of a smelter source since all of these elements are emitted during the copper ore smelting process. Sulfur is also moderately loaded on this factor with a loading of 0.47. It is interesting to note in this analysis that Pb is loaded onto the smelter factor and not some other factor related to vehicular emissions. A second factor shows high loadings for Si, K, Ca, Ti, and Fe and is suggestive of crustal sources in the region. A third factor shows intermediate loadings for S, Ni and Sn. A fourth factor shows loadings for Br, and Cl and V, Cr, Mn and Ge are loaded on a fifth factor. While the first two factors can be physically related to sources within the region, the same cannot be conclusively said for the last three factors. Day and night subsets of the data were similarly analyzed by factor analysis with results showing similar characteristics to the combined day and night data set.

[3] Varimax rotation is one of the matrix manipulation techniques used within the factor analysis routine to improve the resolution of the variables into groups of factors.

Table 18
Normalized Fine Particle Factor Analysis Results

Element	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
SI	0.02	0.98	-0.01	0.02	0.07
S	0.47	-0.10	0.51	0.22	0.14
CL	-0.08	-0.03	-0.20	-0.63	-0.07
K	-0.02	0.71	0.14	-0.16	-0.06
CA	0.01	0.95	-0.03	-0.03	0.03
TI	-0.03	0.75	-0.07	0.00	0.36
V	0.14	0.10	-0.04	0.06	0.54
CR	0.00	0.32	0.06	0.11	0.67
MN	0.32	0.56	0.29	-0.11	0.50
FE	0.18	0.90	0.11	0.10	0.14
NI	0.06	0.00	0.70	-0.14	0.26
CU	0.89	0.15	0.18	0.02	0.23
ZN	0.71	0.12	0.20	0.07	0.01
GA	0.03	-0.05	0.02	0.20	0.02
GE	0.35	-0.01	0.09	0.15	0.55
AS	0.82	-0.03	0.24	0.08	0.22
SE	0.51	0.01	-0.13	-0.01	0.31
BR	0.08	-0.12	0.33	-0.73	-0.04
RB	0.31	0.58	-0.17	-0.08	0.41
SR	-0.04	0.69	0.04	0.05	0.01
PB	0.75	-0.07	0.22	-0.14	-0.08
ZR	-0.11	0.40	0.23	0.25	0.23
MO	0.50	0.15	0.37	0.32	0.12
AG	0.65	0.01	-0.18	0.00	0.16
CD	0.59	0.03	0.29	0.09	-0.01
SN	0.31	0.05	0.72	-0.10	-0.01
SB	0.46	-0.12	0.39	-0.35	-0.10
I	0.33	0.02	0.60	0.22	-0.25
BA	0.03	0.31	0.59	0.15	-0.07
Expl.Var	4.86	5.33	2.94	1.53	2.09
Prp.Totl	0.17	0.18	0.10	0.05	0.07

Factor Analysis on the CPM Data Set

The combined coarse particle data set was analyzed in a similar manner as for the FPM data set. The overall variance in the data set accounted for by the five factors extracted in this solution is given in Table 19. The fit of the factor model to the data set is slightly better for the CPM data set when compared to the FPM data set. The CPM model accounts for about 68% of the variability in the CPM data set as compared to 58% for the FPM data set.

Table 19
Goodness of Fit Results for a 5-Factor Solution of the Normalized CPM Data Set

Factor	Total Variance %	Cumulative Variance %
1	25.0	25.0
2	14.8	39.7
3	10.6	50.4
4	10.4	60.8
5	6.6	67.4

The loadings of the various elements on the 5 factors extracted from this data set are given in Table 20. The first factor shows high loadings for Ti, V, Cr, Ni, Ga, Zr, and Mo. Sources related to this profile are not immediately obvious. A second factor shows high loadings for Cu, Zn and As and is probably related to smelter emissions. The elements of Br, S and Cl are loaded on a third factor and may be related to vehicular sources as evidenced by the presence of Br in this elemental profile. Elements of Si, K, Ca, Ti and Fe are loaded on a fourth crustal factor, while a fifth factor shows loadings for Sb, I and Ba and Cd for which a physical source is not obvious. Sulfur is loaded at a lower (0.34) level in the CPM smelter factor than its loading of 0.51 in the FPM smelter factor. This may be a result of the fact that sulfur is emitted from the process primarily in the gaseous form followed by the formation of particulate sulfate species in the FPM size category by atmospheric oxidation.

Table 20
Normalized Coarse Particle Factor Analysis Results

Element	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
SI	0.13	0.26	0.13	0.91	-0.01
S	0.14	0.35	0.71	-0.05	0.16
CL	-0.06	-0.11	0.59	0.15	0.06
K	0.18	0.12	0.27	0.90	-0.02
CA	-0.02	-0.15	-0.15	0.55	0.05
TI	0.71	-0.03	0.00	0.58	-0.23
V	0.84	-0.02	0.34	-0.14	-0.11
CR	0.75	0.08	-0.28	0.24	0.01
MN	0.59	0.48	-0.03	0.42	-0.01
FE	0.16	0.55	-0.07	0.66	0.31
NI	0.86	-0.09	0.15	-0.31	-0.07
CU	0.07	0.87	-0.28	0.15	0.08
ZN	0.06	0.76	0.15	0.11	0.12
GA	0.81	-0.11	0.13'	-0.01	-0.02
GE	0.50	-0.01	-0.43	-0.06	0.15
AS	-0.04	0.89	-0.02	-0.11	0.09
SE	0.32	0.62	0.29	-0.33	-0.20
BR	0.00	0.09	0.91	0.05	-0.11
RB	0.51	0.27	0.25	0.16	-0.25
SR	-0.07	-0.03	0.30	0.48	-0.06
PB	-0.01	0.66	0.48	0.24	0.07
ZR	0.72	-0.10	-0.24	0.31	-0.05
MO	0.81	0.30	-0.06	-0.13	0.06
AG	0.30	0.10	-0.15	0.16	0.04
CD	0.55	0.14	0.10	0.23	-0.08
SN	0.53	0.13	-0.34	-0.02	0.12
SB	-0.17	0.16	0.06	-0.11	0.86
I	-0.16	0.01	0.06	-0.05	0.88
BA	0.24	0.11	-0.12	0.26	0.75
Expl.Var	6.20	4.02	3.02	3.84	2.47
Prp.Totl	0.21	0.14	0.10	0.13	0.09

5.4.8.3 Source Strength Estimation by Tracer Elements

Use of the CMB7 receptor model on the data set collected during this short term study was beyond the scope of analysis in this study. Estimates of the degree to which selected sources contributed to the overall FPM and CPM were obtained, however, by using a number of unique tracer elements for several sources known to exist in the El Paso-Cd. Juarez region. The degree to which soil contributes to measured FPM and CPM was estimated by taking literature-derived values for the Si mass fraction of soil in both the fine and coarse size fractions [Watson, 1979]. Mass fractions of Si in FPM and CPM were 259 and 321 milligrams per gram of soil, respectively, resulting in multipliers of 3.86 and 3.12 to scale from Si concentrations to crustally-derived FPM and CPM respectively. The following calculation was carried out for each 12-hour sampling period:

$$\%FPM_{soil} = \frac{Si_{FPM} \cdot M}{FPM} \cdot 100 \qquad (1)$$

where $\%FPM_{soil}$ is an estimate of the percent mass fraction of total FPM that is derived from the crustal source, Si_{FPM} is the Si concentration measured in the 12-hour dichot filter sample, M is the multiplier used to scale Si to crustal FPM, and FPM is the measured fine particle mass concentration in the 12-hour sample. In this calculation we assume that airborne Si is unique to the crustal source. In other words, all Si detected on the filter has crustal origins. Similar calculations were carried out for the coarse fraction measurements using a different multiplier and CPM instead of FPM. The results for both fine and coarse fractions are plotted as frequency histograms in Figures 51 and 52 for all 12-hour periods. For the fine fraction, estimated crustal source strength ranges from about 4 to 18 percent with most occurrences falling in the range of 4 to 8 percent. The average value was 6 ± 3 percent. Estimates for soil contribution to the coarse aerosol fraction range from a low of about 5 percent to a high of 60 percent. The median value for the coarse size fraction falls at about 30 percent. These estimates reveal that which is already known to be true for most urban air masses--crustal sources such as windblown dust or entrained dust from vehicular activity constitute a significant fraction of the CPM size category.

Similar calculations were carried out using As as a unique tracer for smelter sources in the region. Literature values for the elemental concentrations measured in smelter plumes were used to estimate the mass fraction of As in both fine and coarse sizes at about 4 percent [Small, 1981]. This value corresponds to a multiplier of 25 for use in the calculation for smelter source strength analogous to that shown in equation 1 for the crustal source. Figures 53 and 54 give frequency distributions for the smelter source strength in both the fine and coarse size fraction for all 12-hour sampling periods. The smelter contribution to FPM is the highest of the two sizes with a median value of about 2 percent. Smelter contribution to the coarse fraction is an approximately eight-fold less with a median value of about 0.25 percent.

Source strength estimates for vehicular and biomass burning were carried out using Pb and K as elemental tracers. Lead, although not uniquely identified with vehicular sources, was nonetheless used to determine an upper bound estimate for vehicular source contribution to both fine and coarse aerosol. For this calculation we assumed that all airborne Pb originated from vehicles burning leaded fuel. We further determined through conversations with local air quality officials that about 95% of all fuel consumed in El Paso is unleaded gasoline and that about 80% of fuel consumed in Cd. Juarez is unleaded [Reynoso, 1994]. We used the total VMT results for El Paso and Cd. Juarez, posted in Table 7, to calculate a weighted average of fuel type consumption for both cities at 91% unleaded and 9% leaded fuel. From the literature, we used 0.2 as an estimate of the ratio of fine particle Pb to total FPM for vehicular sources burning leaded fuel [Pierson, 1976 and Watson, 1979]. Thus increasing the measured Pb value by a factor of 5 provides a measure of vehicular FPM, assuming that all vehicles are burning leaded fuel. Since only 9% of the fuel consumed is leaded fuel in the region, we incorporate another multiplier of 11.1 to account for those vehicles burning unleaded fuel, if we conservatively assume that vehicles burning unleaded fuel emit the same amount of fine particle aerosol as those burning leaded fuel. The following expression then yields a worst case estimate of FPM from vehicles:

$$\%FPM_{vehicle} = \frac{[Pb]*5*11.1}{FPM}*100 \tag{2}$$

A similar expression was used for estimates of vehicular source contribution to the coarse particle fraction. In this case a multiplier of 6.76 was used instead of 5 to account for lower Pb emissions in the coarse particle fraction [Watson, 1979]. Figures 55 and 56 give estimates of the percent contribution of the vehicular source category to overall FPM and CPM for all sites and sampling periods, using the assumptions noted above. We are careful to point out that these estimates represent an upper bound since other sources of aerosol Pb exist within the airshed. The overall average contribution of the vehicular source to FPM was 31 ± 18%, and 10 ± 6% to CPM. The range of contribution for both size categories is quite variable ranging from 10 to 55 percent for the fine fraction and 3 to 20 percent for the coarse fraction.

A similar calculation was carried out using K as a tracer for biomass burning. We corrected the total K measured on the filter for that contribution from crustal sources by using the ratio of soil K to soil Si. We used values of 0.040 for the fine fraction and 0.069 for the coarse fraction as reported in the literature [Watson, 1979]. Crustal K can be estimated taking the product of Si concentration and the K_{soil}/Si_{soil} ratio if one assumes that all Si is crustally derived. The expression used to determine FPM derived from vehicular sources for a particular sampling period follows:

$$FPM_{biomass} = [K-(K*\frac{K_{soil}}{Si_{soil}})]*100 \tag{3}$$

where $FPM_{biomass}$ is the fine aerosol concentration attributable to biomass burning in a particular 12-hour sample, K is the total potassium concentration measured on the filter with K_{soil} and Si_{soil} the soil composition of the two elements as noted above. The multiplier in this case is 100, which approximates the range of literature values for the mass fraction of K in fine and coarse biomass smoke [Hopke, 1985]. Figures 57 and 58 show estimates of the percent contribution of the biomass source category to total FPM and CPM respectively. The distribution is quite narrow for the fine fraction with well over half of the values falling between 50 and 60%. The mean contribution of this source category to the fine fraction aerosol was 53 ± 14%. A lower mean contribution of 31 ± 8% was noted for the coarse aerosol size fraction.

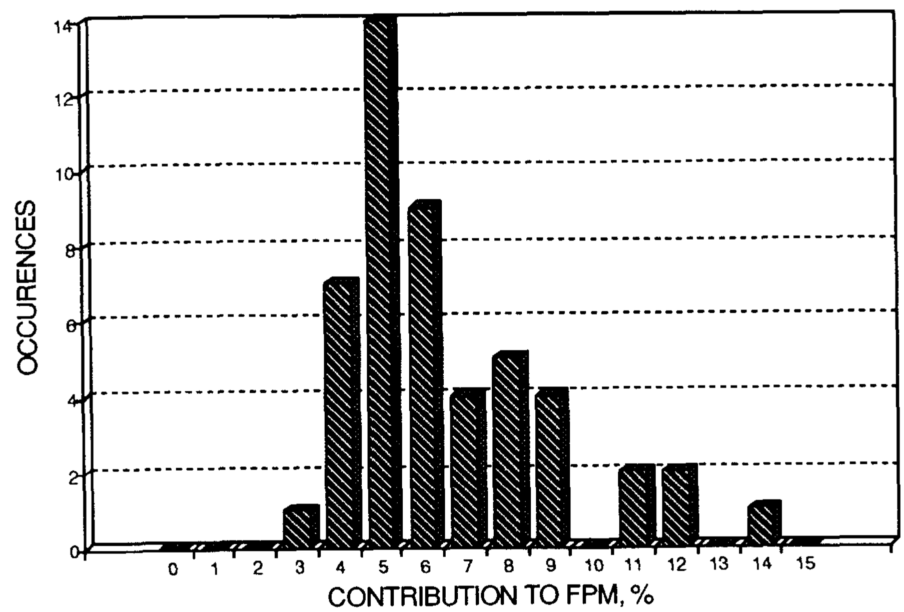


Figure 51 Estimates of crustal source contribution to FPM for all sites and sampling periods.

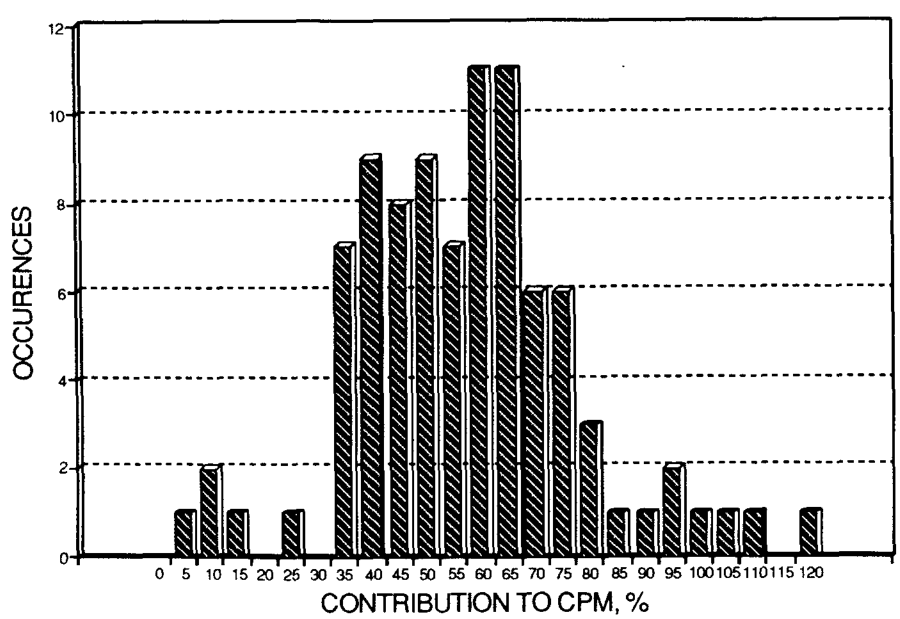


Figure 52 Estimates of crustal source contribution to CPM for all sites and sampling periods.

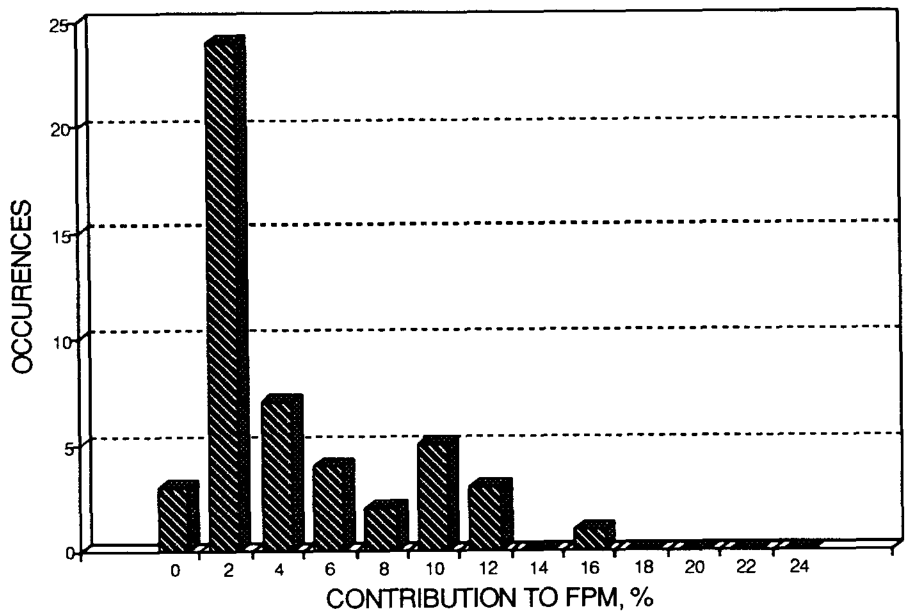


Figure 53 Estimates of smelter source contribution to FPM for all sites and all sampling periods.

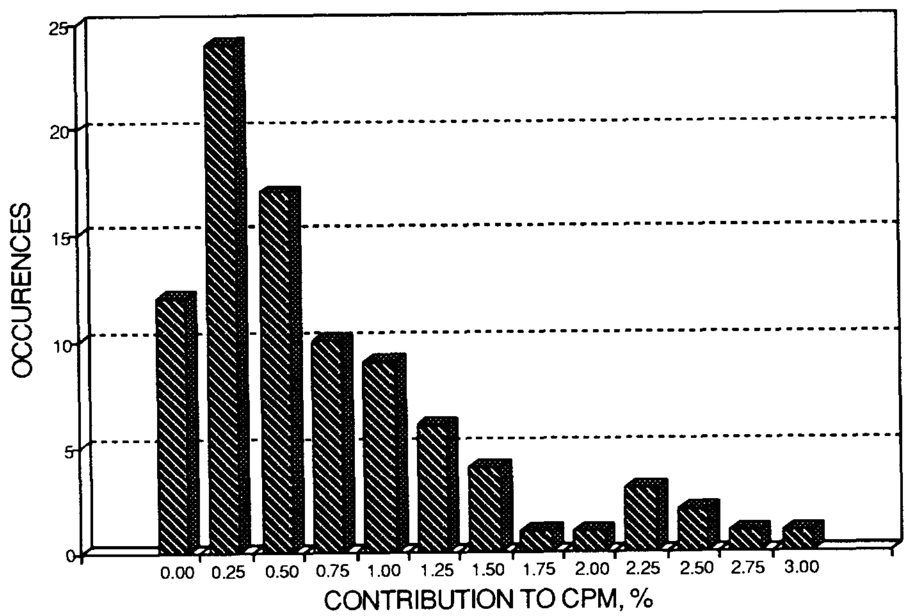


Figure 54 Estimates of smelter source contribution to CPM for all sites and sampling periods.

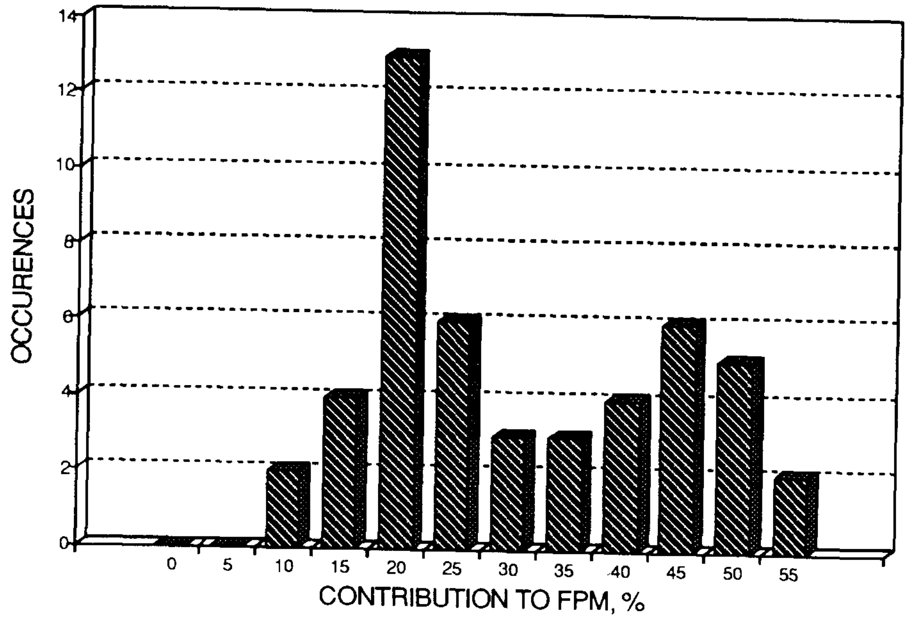


Figure 55 Estimates of vehicular source contribution to FPM for all sites and sampling periods.

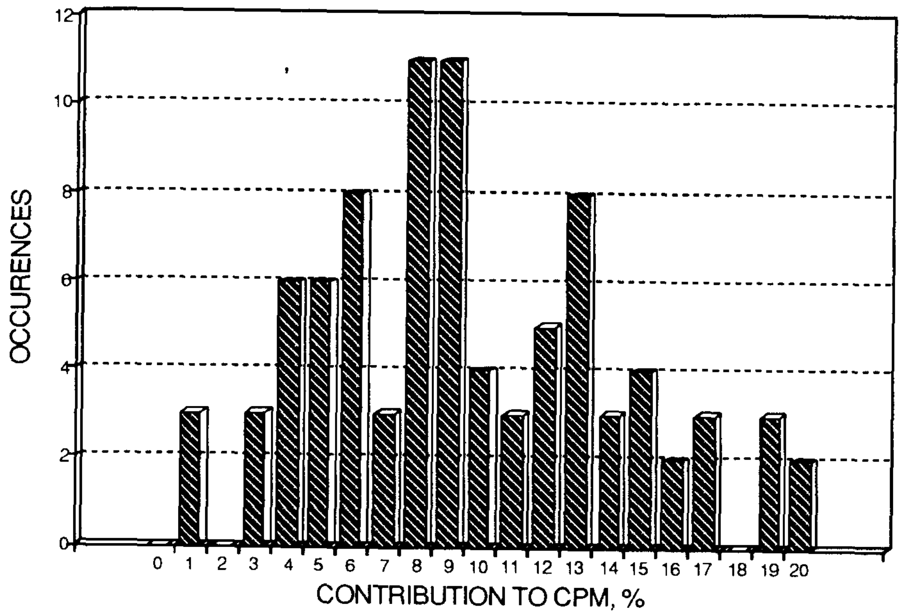


Figure 56 Estimates of the vehicular source contribution to CPM for all sampling sites and periods.

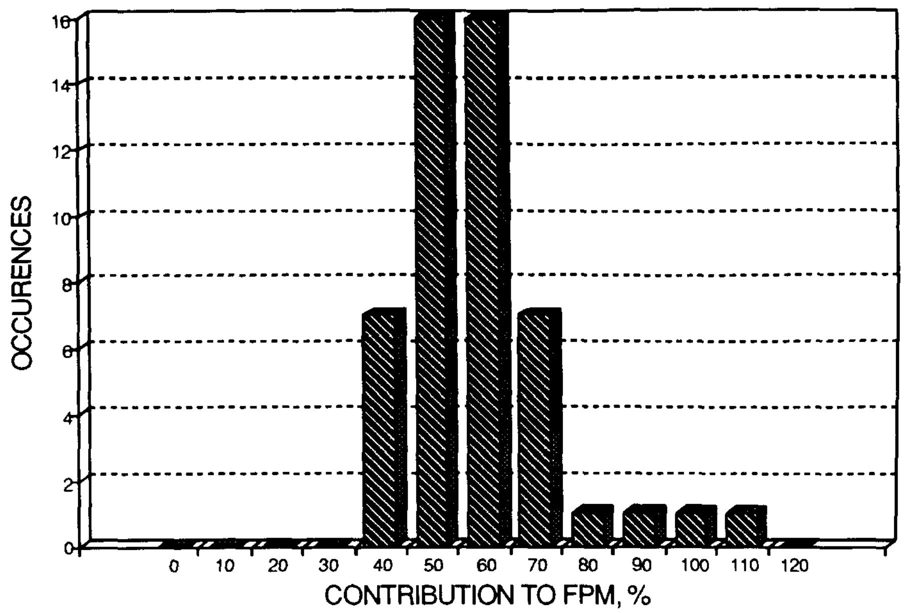


Figure 57 Estimates of biomass combustion source contribution to FPM for all sampling sites and periods.

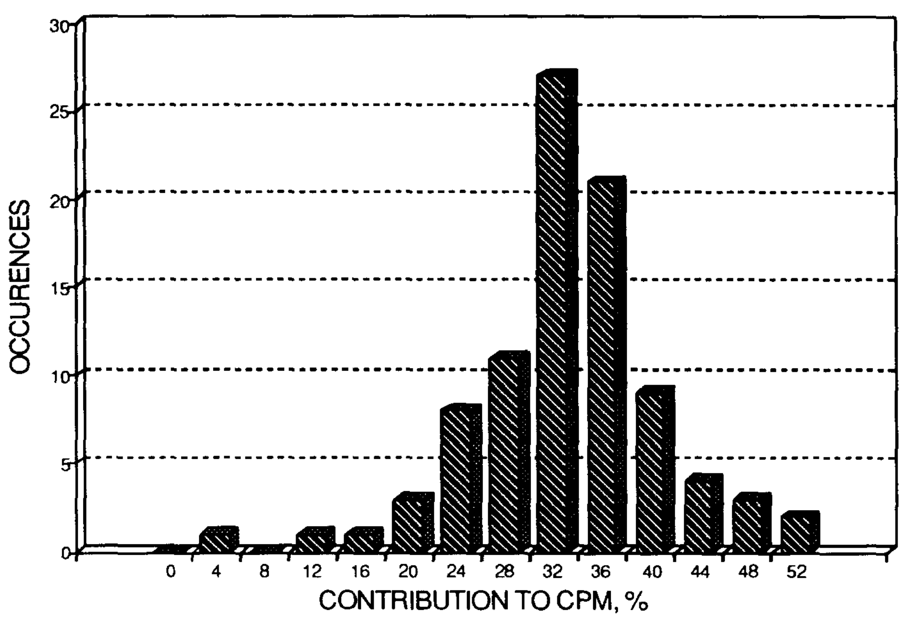


Figure 58 Estimates of biomass combustion source contribution to CPM for all sampling sites and periods.

Overall summary of source contributions to FPM, CPM and PM_{10}

A summary of average source strength estimates for both the fine and coarse aerosol fractions using tracer elements is given in Table 21. The overall composition of PM_{10} during this winter season study was 39% FPM and 61%CPM as given earlier in Table 12. Using this PM_{10} composition, a weighted average of the source strength estimates given in Table 13 was calculated for the PM_{10} size category and is shown in Figure 59. Our estimates reveal that biomass combustion and crustal sources together account for nearly 80 percent of PM_{10} during the winter season. The vehicular category is at about 20% and about one-fourth of the biomass and crustal categories combined. The smelter category is a minor contributor at a level of about 2%. It is arguable that the crustal category is to a large extent influenced by the vehicular category since the use of vehicles on both paved and unpaved roadways will result in the entrainment of soil particles into the air. Furthermore, it is readily apparent that many miles of unpaved roadways exist in the residential sections of Cd. Juarez.

Table 21
Summary Source Strength Estimates for Fine and Coarse Aerosol Fractions

Source Category	Fine Particle Fraction (%)	Coarse Particle Fraction (%)
Vehicular	31 ± 18	10 ± 6
Biomass Combustion	53 ± 14	31 ± 8
Smelter	4 ± 5	<1 ± 1
Crustal	6 ± 3	57 ± 22

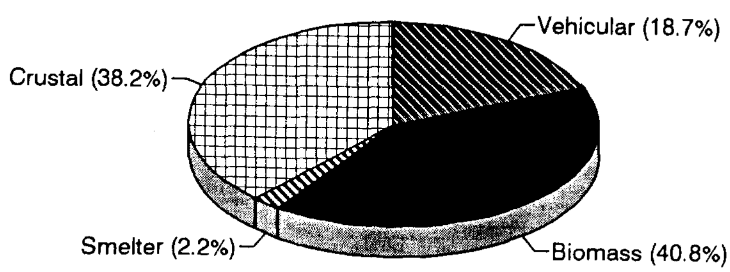


Figure 59 Estimates of source category contribution to total PM-10 during the winter season El Paso-Cd. Juarez.

These results reveal several important features of winter season air quality in the El Paso del Norte airshed. First, our estimates reveal that biomass combustion sources are a significant contributor to PM_{10}. The use of wood products for residential heating and brick kiln fuel appears to be a significant source of PM_{10} during the winter season. The extent to which wood combustion is used for residential home heating in El Paso has not been reported in any of the reports reviewed as a part of this effort. Wood or other biomass combustion in Cd. Juarez is recognized both in the brick making industry and for residential home heating since many Cd. Juarez residences lack natural gas or electric central heating systems. Further investigations into the extent of biomass combustion would be warranted to confirm the estimates derived here. Secondly, the crustal source is a major contributor to the PM_{10} category and is probably very closely tied to vehicle use in Cd. Juarez. In the studies reviewed in this work, no comparison is made between El Paso and Cd. Juarez with respect to unpaved roadways. However, in general unpaved roadways are much more prevalent in Cd. Juarez than in El Paso. The results from this study would indicate that programs to curtail biomass burning and to pave roadways would do much to control the PM_{10} levels encountered during the winter season in this particular airshed.

Further refinement of source strength by receptor modeling is best carried out with use of the CMB model. As noted earlier, however, effective use of this model is not without its own set of problems. The analyst is faced with the selection of appropriate source profiles for use in the statistical fitting routines by either the judicious use of library source profiles or through the collection of source profiles in the El Paso-Cd. Juarez area at considerable effort and expense. Short term studies such as the one discussed here prove useful by providing initial estimates of source category strength from which follow-on studies can be thoughtfully planned and executed.

6.0 Summary Conclusions and a Forward Look

The most important findings from the studies reviewed in Sections 3 and 4 of this report are summarized along with the major findings from the short term winter PM_{10} study presented in Section 5. A brief review of some recent technological developments relevant to air quality issues in the El Paso del Norte region is also given.

6.1 Summary Findings

Industrial stationary sources do not contribute significantly to airborne particulate matter in the El Paso del Norte region - Studies in the 1980's focusing on total suspended particulate matter and more recent studies dealing with PM_{10} both reveal that large industrial stationary sources such as copper smelters in the region are minor contributors to winter season airborne particulate matter.

Winter season PM_{10} levels are highest in the Cd. Juarez-El Paso downtown areas and in general show a concentration gradient increasing toward Mexico - A number of studies, among them the EPA-EMSL airborne lidar study, EPA-6 saturation PM_{10} study, and the short term winter PM_{10} study, all reveal higher PM_{10} levels as one moves toward Cd. Juarez. Further indirect evidence for this concentration gradient comes by way of the TNRCC PM_{10} SIP analysis which reveals that no exceedences of PM_{10} are predicted in El Paso if only El Paso particulate matter sources are taken into account. In actual studies, however, PM_{10} concentration levels in excess of air quality standards are encountered on both sides of the border.

Emissions from the average vehicle in Cd. Juarez are about three-fold higher than from the average vehicle in El Paso - The University of Denver remote sensing studies for tailpipe CO and hydrocarbons show that while the amount of pollutants emitted from a high-polluting car is the same in both Cd. Juarez and El Paso, there are more of these high-polluting cars operating in Cd. Juarez than in El Paso. Other studies undertaken to characterize the age of the vehicular fleet in Cd. Juarez reveal that the average age of the fleet is older in Cd. Juarez than in El Paso. This observation is consistent with the measured higher tailpipe emissions in Cd. Juarez.

Vehicle miles traveled in El Paso are about three-fold higher than in Cd. Juarez - Results from a series of studies by the Texas Transportation Institute on vehicle usage in Cd. Juarez reveal about 3.4 million VMT in Cd. Juarez as compared to 9.9 million VMT in El Paso. Per capita mileage in El Paso is about six-fold higher than in Cd. Juarez revealing very different vehicle usage patterns in the two cities. Should Cd. Juarez residents adopt US driving habits, vehicular emissions could significantly increase in the Paso del Norte region.

Winter stagnation events and complex terrain significantly limit pollutant dilution within the region - Meteorological data taken during the PM_{10} short term study confirm the presence of very shallow vertical mixing heights in the evening and early morning hours during winter season. Wind flow at various meteorological monitoring locations throughout the El Paso del Norte region reveal local terrain influence during winter stagnation periods. Wind fields predicted by the Diagnostic Wind Field Model show general agreement with observed winds. A rigorous comparison was not carried out as a part of this study however. In some test cases abnormal discontinuities in the predicted wind fields were observed suggesting that optimization of the model may be required to obtain representative results.

Winter season PM_{10} in the Paso del Norte region reaches levels in excess of the National Ambient Air Quality Standard - Analyses completed by the TNRCC as a part of the short term winter PM_{10} study revealed numerous exceedences of the 24-hour PM_{10} standard at both Cd. Juarez and El Paso sites during the winter season study period. In some cases, PM_{10} levels three-fold higher than the air quality standard were observed.

Aerosol carbon is a major constituent of fine, coarse and PM_{10} aerosol in the region - Carbon species measurements of collected particulate matter reveal aerosol carbon composition much like that observed in other urban areas. High levels of both elemental and volatile carbon are observed and originate from vehicular, biomass combustion and other local combustion sources. Limited measurements of individual toxic aerosol species such as benzo(a)pyrene show that, in general, these vary proportionately with overall aerosol carbon levels. The relatively high levels of elemental or soot carbon have important implications for visibility in the region as well since elemental carbon is an important contributor to visibility reduction.

Crustal and biomass combustion sources together constitute nearly 80 percent of the winter season total PM_{10} measured in the Paso del Norte region - Preliminary estimates of source category strength using tracer elements reveal that these two sources are the major contributors to winter season PM_{10}. Average contribution of the crustal source to PM_{10} is about 40%. The crustal source is understood to be closely linked to vehicular sources which are estimated to contribute no more than 20% to total PM_{10}. Vehicle traffic on many unpaved roadways, prevalent in Cd. Juarez residential areas, results in the suspension of both fine and coarse fraction crustal material, thus linking the vehicular and crustal source categories. The use of soil-corrected potassium as a tracer for biomass combustion reveals about 40% average contribution of this source to PM_{10} as well.

6.2 New Technologies

Several recent studies have employed new technologies to further explore air quality issues in the El Paso del Norte region. The EPA is interested in employing remote sensing and other new techniques to the El-Paso-Cd. Juarez air pollution problem. Thorough understanding of instrument performance and data validation of particular techniques are needed prior to wide-spread use of such techniques for compliance monitoring however. These new technologies are briefly described below.

6.2.1 Lidar Systems

Los Alamos National Laboratories Mini-Lidar

Los Alamos National Laboratory has on two occasions field tested a new "mini-lidar" system to map aerosol spatial distribution and to estimate wind fields in the El Paso-Cd. Juarez region. This is a relatively small, transportable, ground-based lidar system that measures elastic back scatter from airborne particles along the laser beam path. Like any lidar system, the travel time of the light pulse out and it reflection back to the detector is used as a measure of the distance that the aerosol is from the lidar. The intensity of return is used to gauge the amount of aerosol as a function of range from the lidar. The lidar is fixed to a gimble mount along with receiving optics so that the beam can be scanned over a wide path thus allowing aerosol density mapping.

Further applications are being explored with this system that involve the estimation of wind fields by tracking aerosol features in the lidar return signal over time. At the present time this wind field determination not straightforward, being computationally intensive and requiring considerable analyst intervention in the data processing steps. The research goal however, is to develop a system that can map out wind fields, giving both wind direction and speed over time in a gridded format using the scanning lidar system. The wind field data are desirable for use in pollutant dispersion models that are more accurate than many of the gaussian dispersion models currently in use by the regulatory community.

Sandia National Laboratories UV-DIAL

Sandia has developed a state-of-the-art ultraviolet differential absorption lidar (UV DIAL) for the remote sensing of chemical species in air. Preliminary testing of a prototype system has recently been completed. DIAL is a variation of conventional absorption spectroscopy that has been adapted to provide the range resolution required by many remote sensing applications. In DIAL two laser pulses are transmitted sequentially--one tuned "on" and the other tuned "off" an absorption band of the chemical species of interest. The back scatter of the light pulses from aerosol and gas molecules in the air provides a recording of signal intensity versus time for both pulses. By ratioing the two signals, a range-resolved measure of concentration of the selected molecular species can be obtained. By scanning the pointing direction of the optical system with a moveable mirror system, a full three-dimensional spatial map of species concentration can be recorded in a short time.

The Sandia UV DIAL system is well suited for many different applications in environmental monitoring. The system is housed in a semi-trailer that can be parked in a single location. The concentration of selected species such as ozone or nitrogen oxides can be mapped out over a large (in some cases several kilometer) radius by rotating and tilting the system's scanning mirror. The broad tunability of the laser system provides an unusual degree of flexibility for a UV DIAL system, making it straightforward to tailor sensitivity, range, spectral resolution and temporal resolution for urban pollution applications. For example, understanding the spatial distribution of ozone (both horizontally and vertically) throughout the day may yield important information about localized pollutant sources contributing to the ozone problem.

Sandia National Laboratories UV-Fluorescence Lidar

Sandia researchers have also developed and recently tested a UV-Fluorescent lidar system for the remote detection of selected organic and inorganic pollutants. The system uses a laser pulse to cause electronic transitions in molecules along the beam path. Electromagnetic radiation is emitted as the molecules decay back to their ground state which is, in turn, detected with an optical configuration at the lidar. Frequency-agile lasers enable the wavelength of the outgoing light pulse to be varied which yields chemical specificity for the system, allowing in many cases individual pollutant species such as benzene or toluene to be detected. The fluorescence signal, detected over a wide frequency band, is processed using advanced multivariate algorithms to detect both the amount and range of pollutants from the lidar. Laser beam direction is accomplished with a scanning mirror such that pollutant mapping can be accomplished. Detectability is expected to be in the mid to high parts per billion for many of the organic species commonly encountered in urban air. While this particular device may not be suitable for general ambient air monitoring because of relatively low sensitivity, it may prove useful for the remote detection of stack emissions or fugitive emissions from stationary sources.

6.2.2 Model Development

Various regulatory and research level pollutant chemistry and transport models were briefly described in the review of the SAI report in Section 4.7. In this section we highlight several new approaches to urban air pollution modeling that offer promise for improved pollutant forecasting and air pollution control program evaluation. A number of prognostic models are under continuing development and improvement. These models accept a minimum of meteorological data and from them calculate wind fields over a wide area much like the Diagnostic Wind Field Module of the Urban Airshed Model discussed earlier. A complementary effort is underway to carefully model the emissions from the wide range of vehicles and vehicle usage patterns that occur on time scales as short as minutes in a typical urban area. Such parameters as vehicle count over the roadway system of a city, the operating mode of the vehicle (cold-start, accelerating, decelerating, idling at a traffic light, etc.) are used by the model to estimate pollutant emissions over an entire urban area. Coupling this information with wind field data produced by a prognostic model makes possible the prediction of air quality in an urban area over the duration of a commute period in a wide range of weather and traffic flow patterns. Los Alamos National Laboratories researchers are developing such a system called TRANSIMS. The system is currently in its early stages of development and requires significant computational effort and further understanding of source emission characteristics. Improvements in computer distributed and parallel processing techniques are expected to speed the computational process to the point where urban simulation routines such as TRANSIMS may become a useful tool for city and regional planners at some point in the future.

6.2.3 Complementary Technologies

Many of the new technologies under development offer important advances in ambient air monitoring issues currently faced by such urban areas as Cd. Juarez-El Paso. It is unlikely that any of the technologies noted above will completely replace conventional point monitoring methods currently in use. These technologies undoubtedly will prove useful however in special studies over relatively short time frames such as reviewed earlier in this report. A combination of these new innovations with conventional monitoring and modeling techniques will yield better understanding and predictive capabilities for air quality trends in international urban areas such as El Paso-Cd. Juarez.

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Appendix A

Wind Fields Calculated
by the
Diagnostic Wind Model

for December 8, 1990

Diagnostic Wind Model Graphical Output

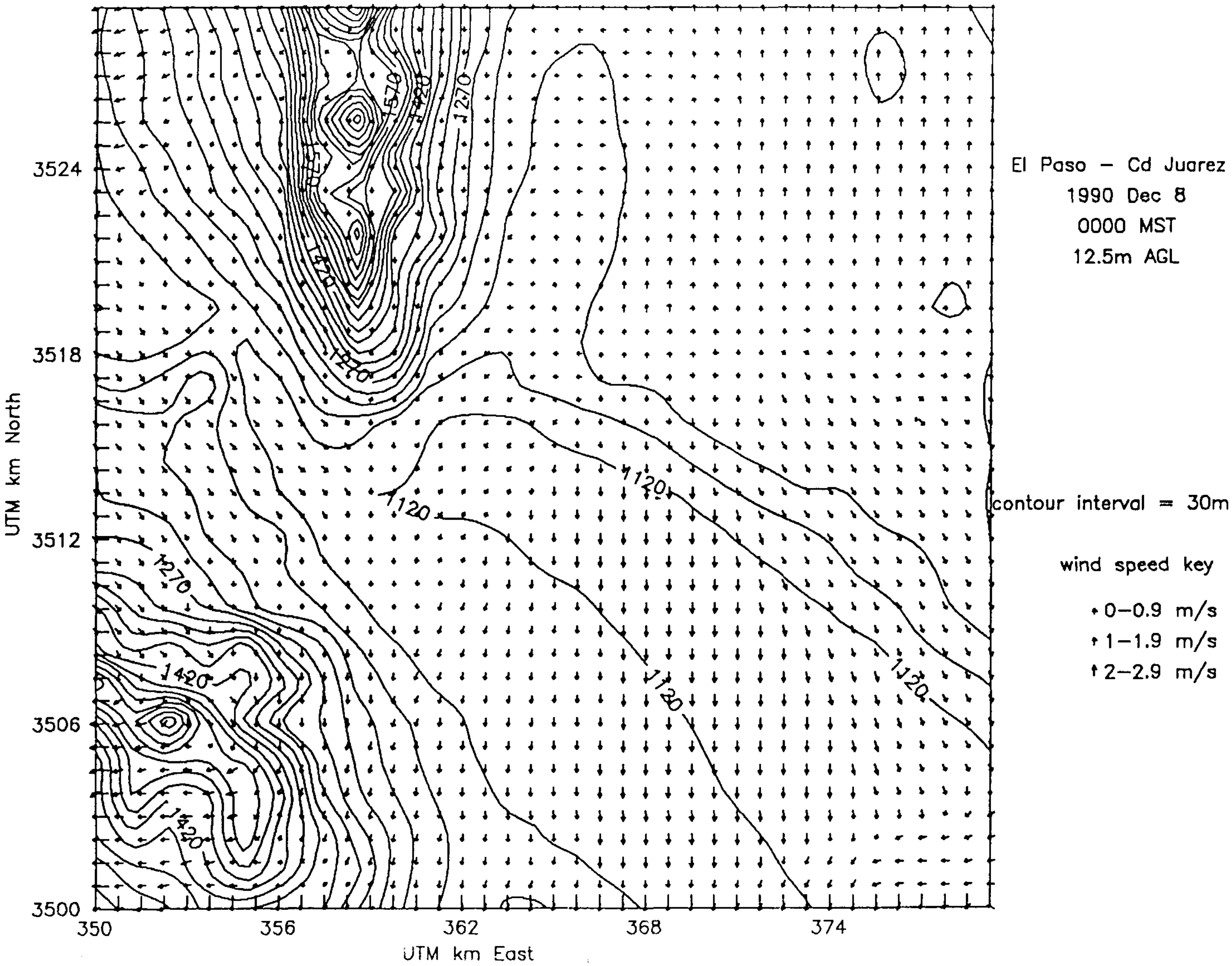
The graphical output for all periods and altitude layers run in this particular investigation are contained in this appendix. The specific times and altitudes are as follows:

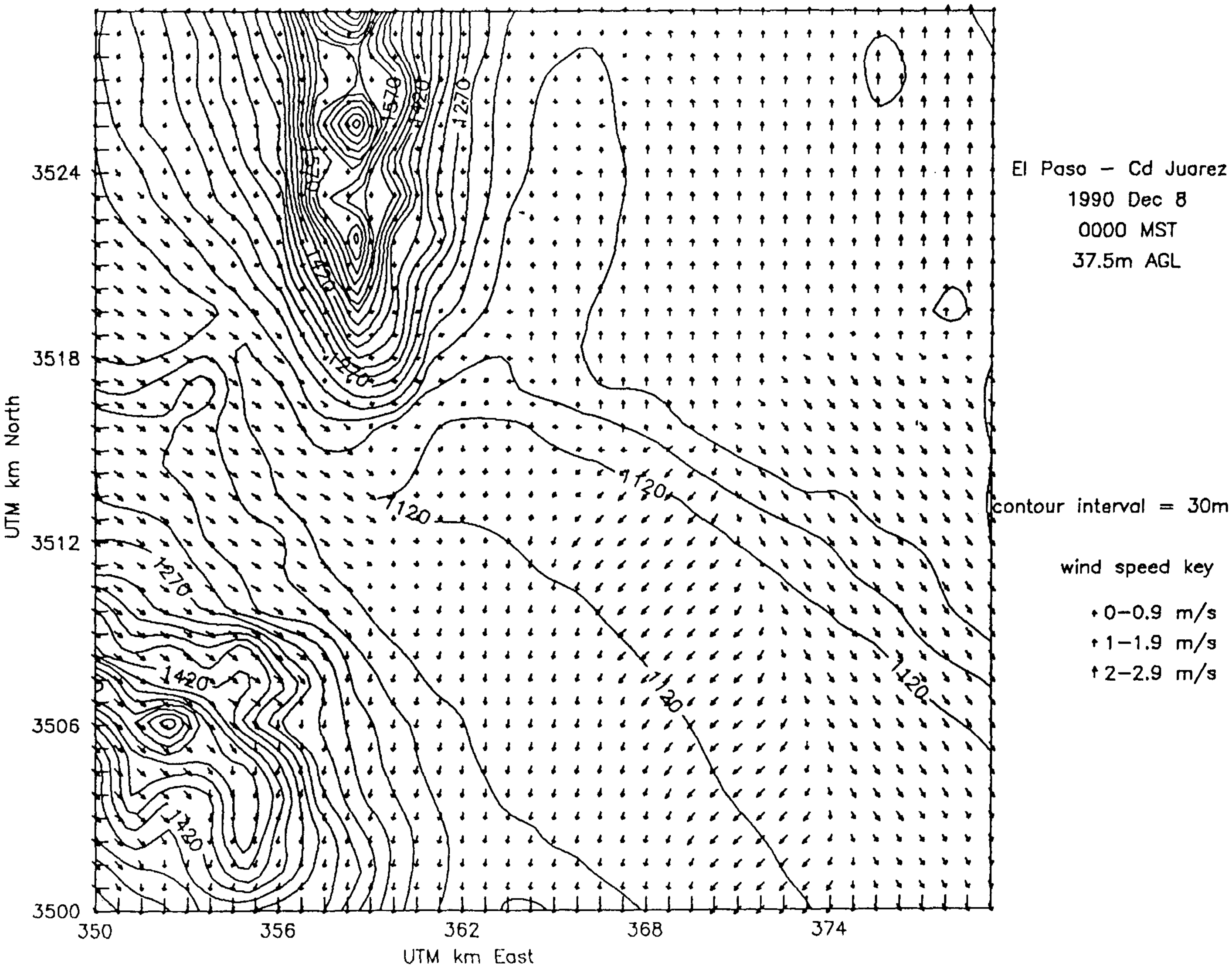
Date: 08-Dec-90

Hours (Mountain Standard Time): 0000, 0400, 0800, 1200, 1600, 2000

Altitude Layers (meters above ground level): 13, 38, 75, 350, 1000

Wind speed and direction are given as a vector at each model grid point. The direction of the vector arrow indicates the direction **toward** which the wind is blowing. The length of the arrow is a measure of the wind speed. A wind speed key to the right of each vector plot gives wind speed ranges in units of meters per second. The local topography is also shown with a contour plot on each of the vector plots with contour altitude markings in meters above mean sea level.


El Paso – Cd Juarez
1990 Dec 8
0000 MST
12.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
UTM km East
3524
3518
3512
3506
3500
350
356
362
368
374
1570
1420
1270
1120



El Paso – Cd Juarez
1990 Dec 8
0000 MST
37.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
UTM km East
3524
3518
3512
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3500
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362
368
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1120
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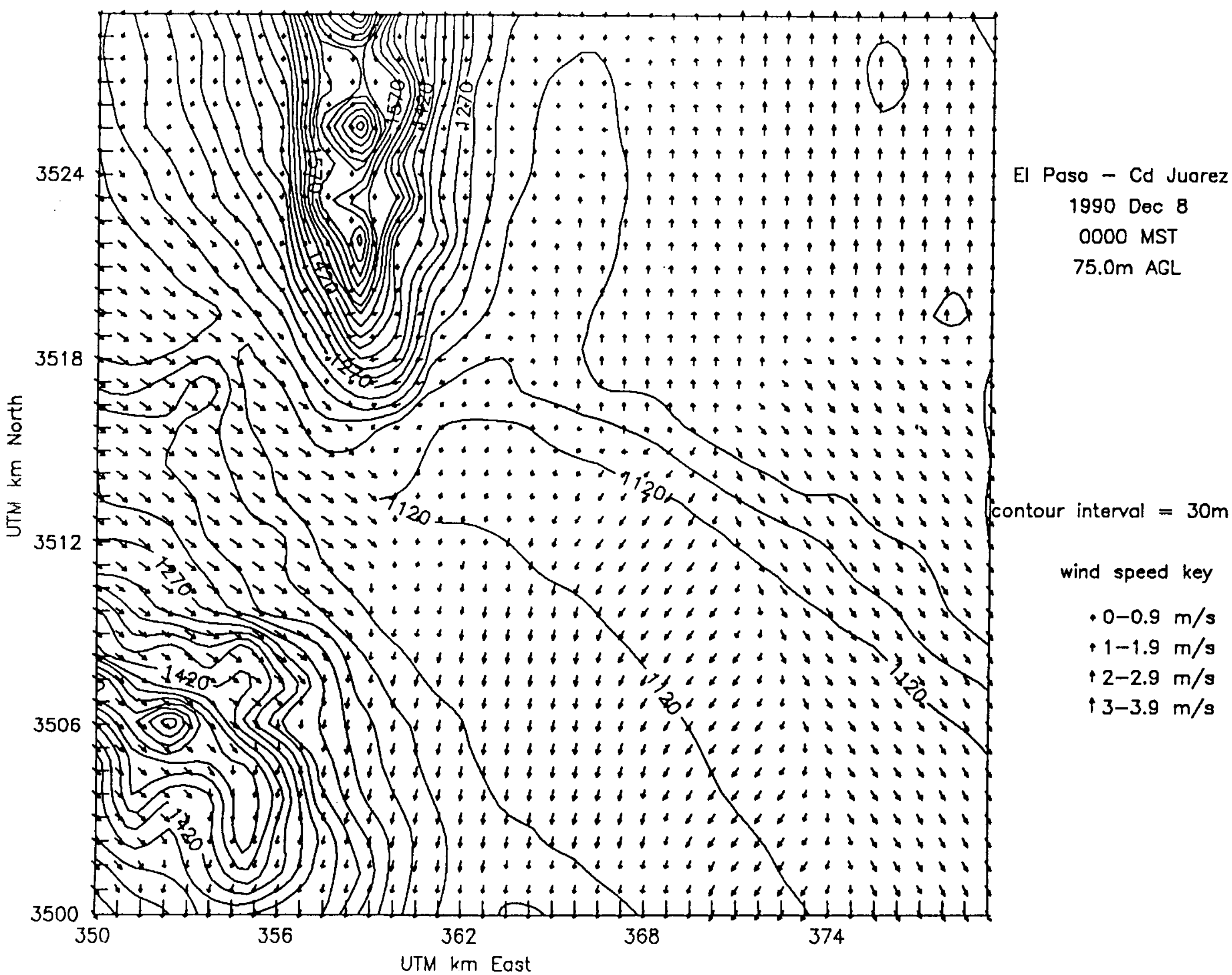
1420
1570


El Paso – Cd Juarez
1990 Dec 8
0000 MST
75.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
UTM km North
UTM km East
3524
3518
3512
3506
3500
350
356
362
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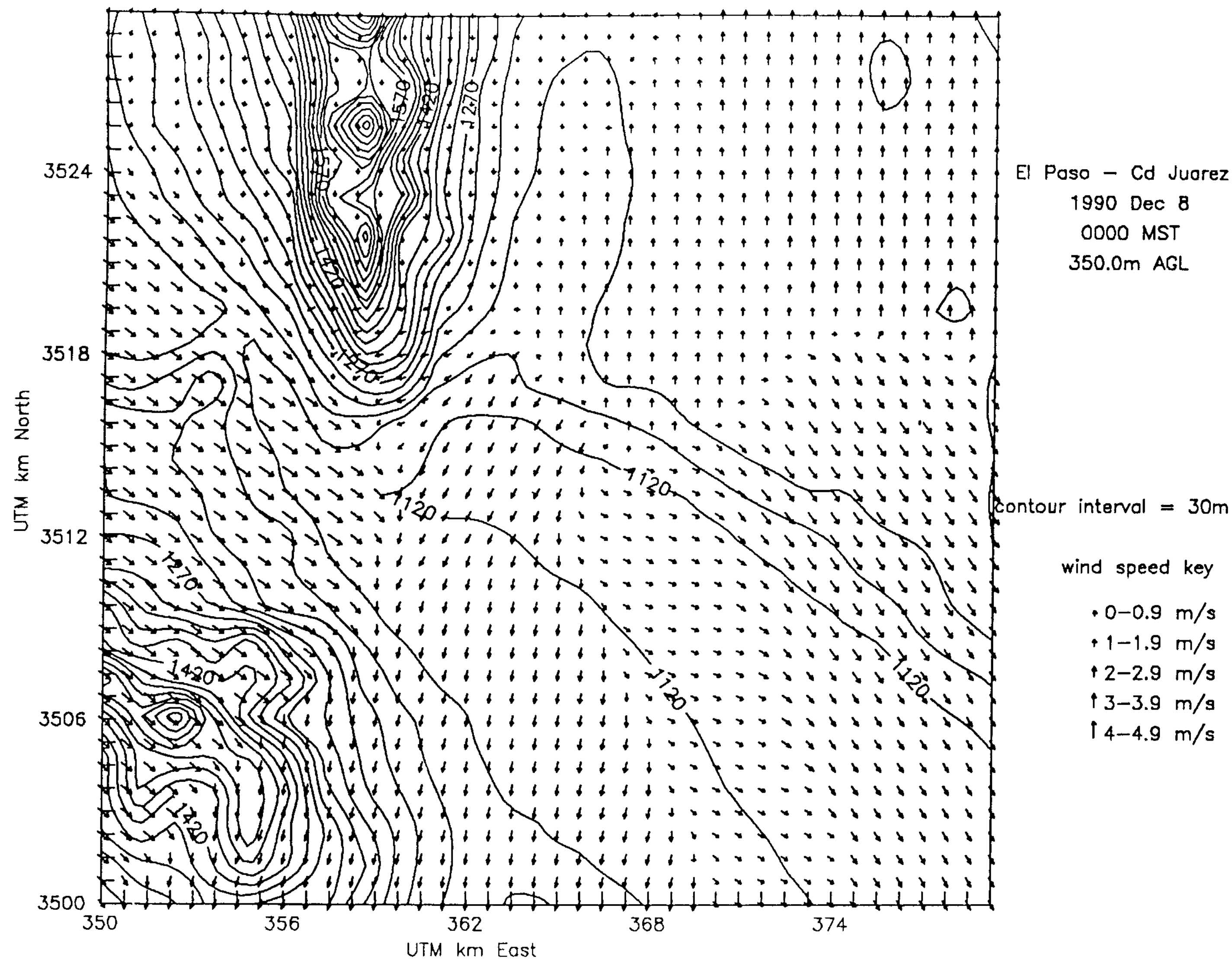
1570


El Paso – Cd Juarez
1990 Dec 8
0000 MST
350.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
4–4.9 m/s
UTM km North
UTM km East
3500
3506
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3518
3524
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368
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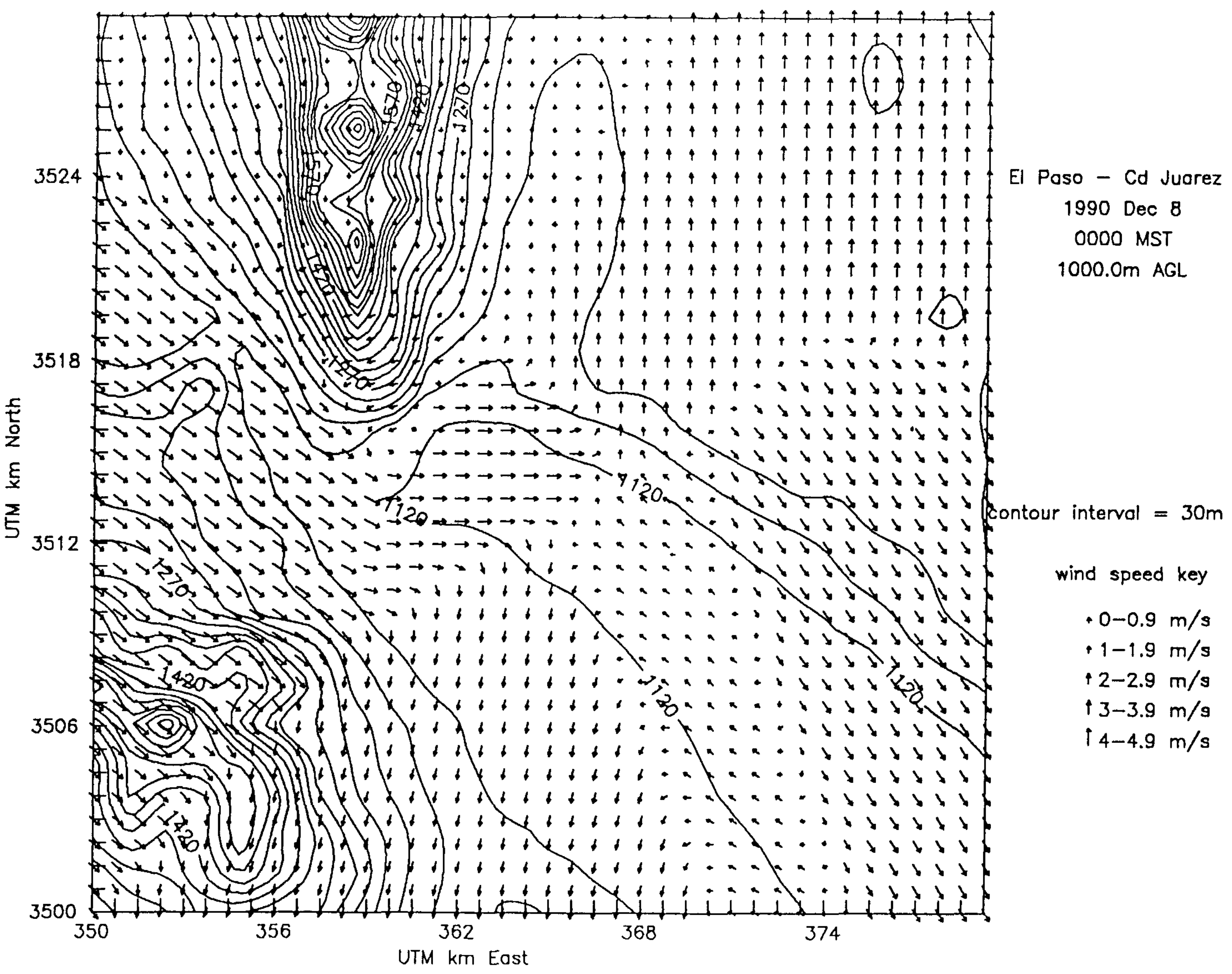
1570



El Paso — Cd Juarez
1990 Dec 8
0000 MST
1000.0m AGL
contour interval = 30m
wind speed key
0-0.9 m/s
1-1.9 m/s
2-2.9 m/s
3-3.9 m/s
4-4.9 m/s
UTM km North
UTM km East
3524
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3506
3500
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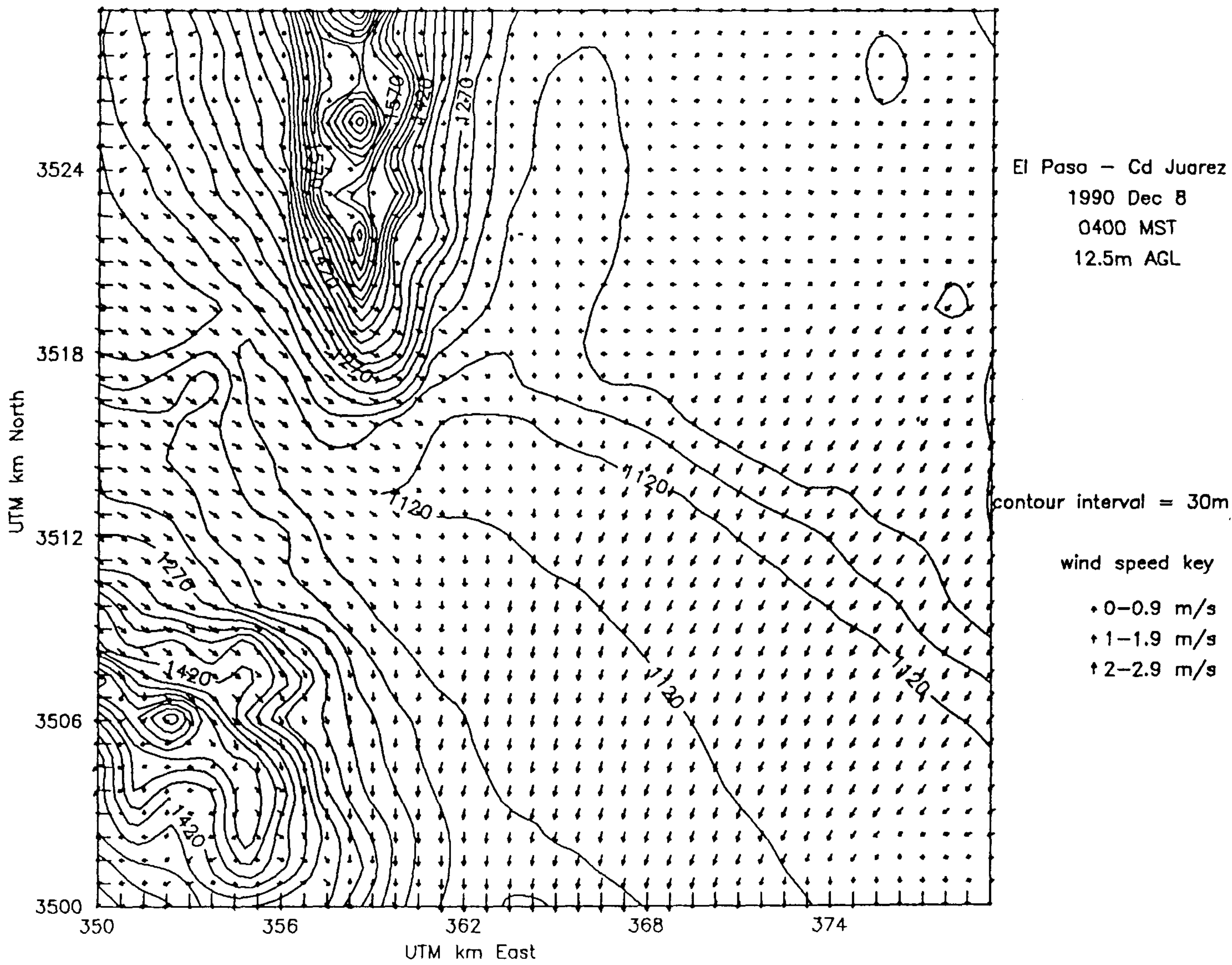

El Paso – Cd Juarez
1990 Dec 8
0400 MST
12.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
UTM km East
3500
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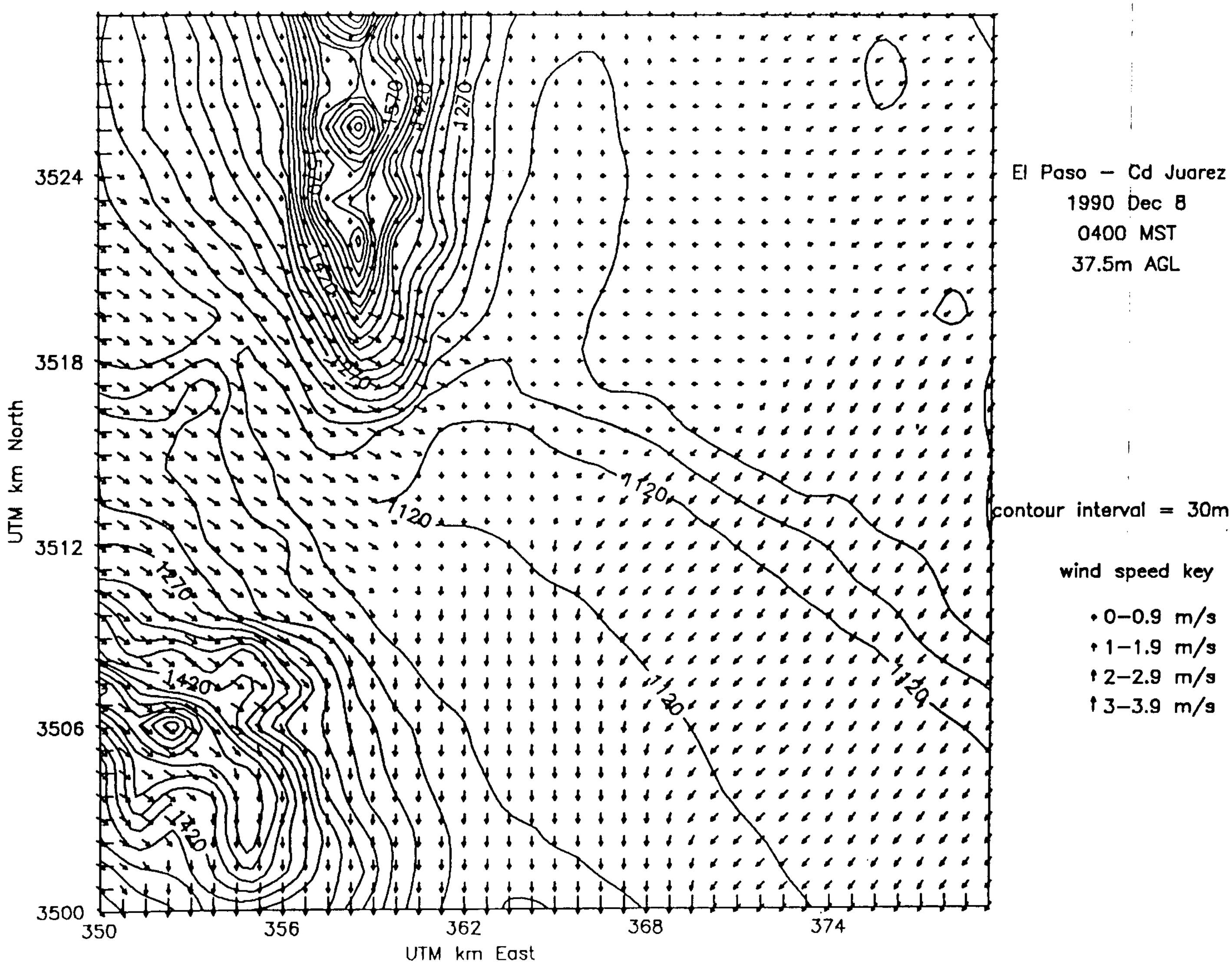
El Paso – Cd Juarez
1990 Dec 8
0400 MST
37.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
UTM km North
UTM km East
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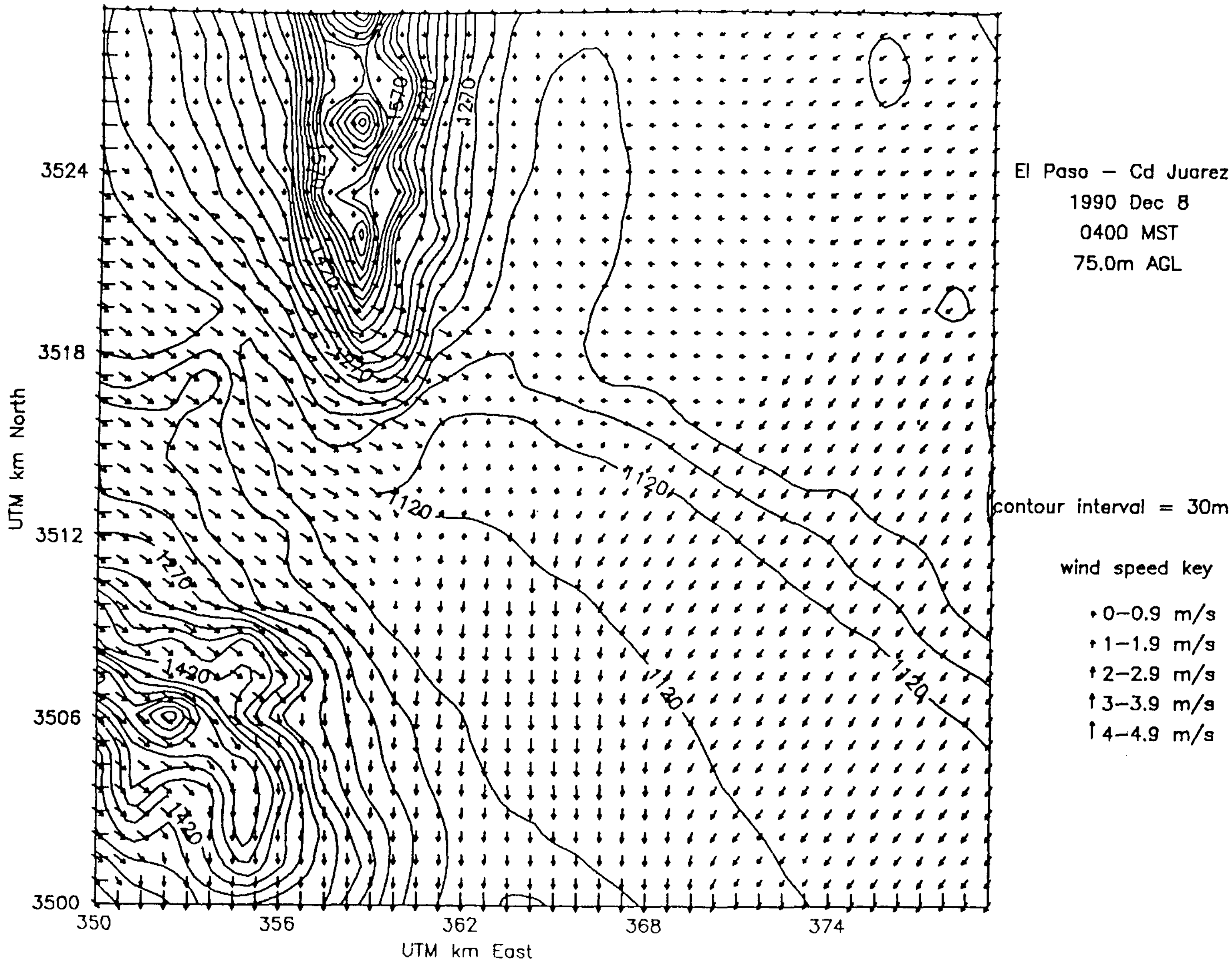
El Paso — Cd Juarez
1990 Dec 8
0400 MST
75.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
4–4.9 m/s
UTM km North
UTM km East
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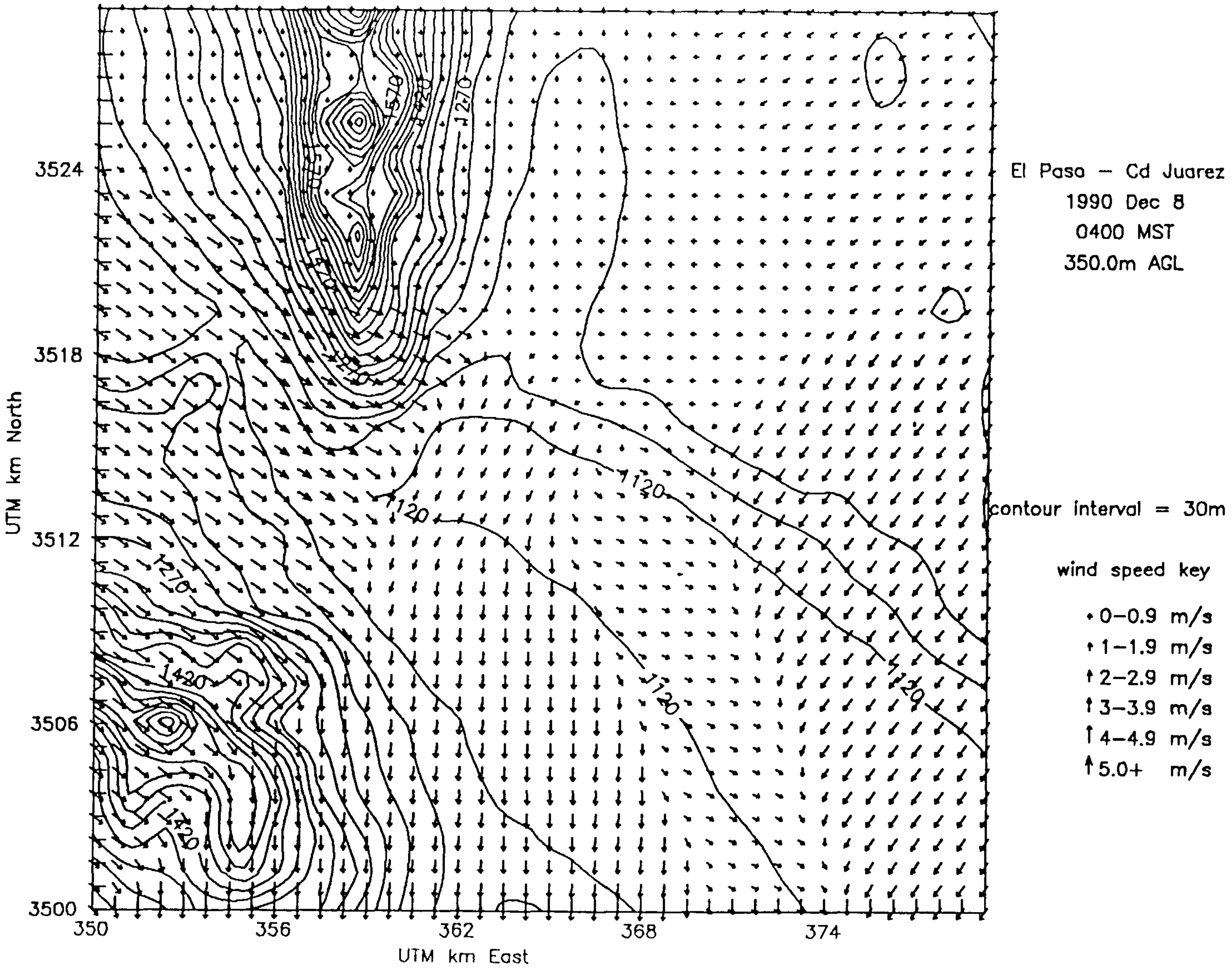

El Paso – Cd Juarez
1990 Dec 8
0400 MST
350.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
4–4.9 m/s
5.0+ m/s
UTM km North
UTM km East
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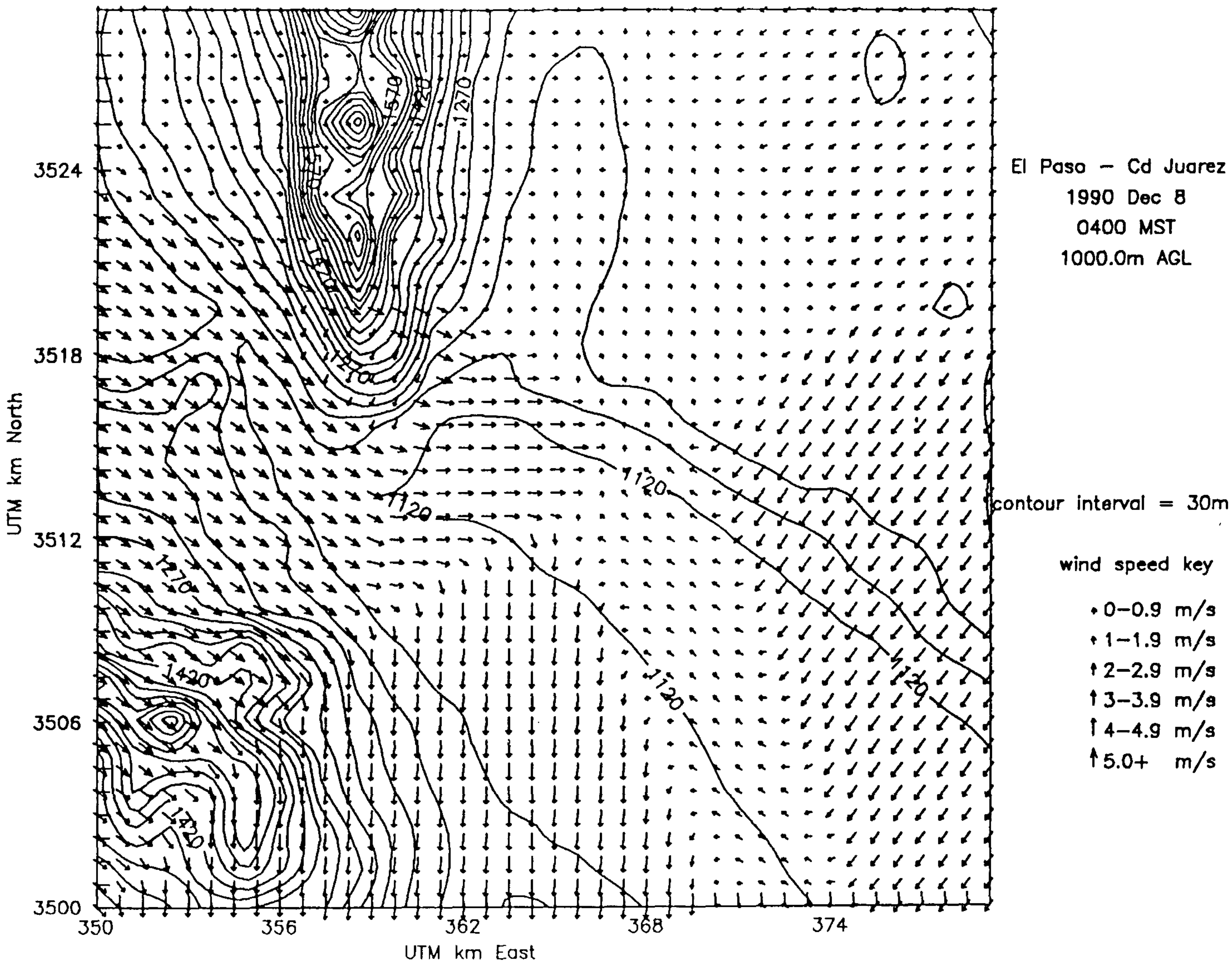

El Paso – Cd Juarez
1990 Dec 8
0400 MST
1000.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
4–4.9 m/s
5.0+ m/s
UTM km North
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UTM km East
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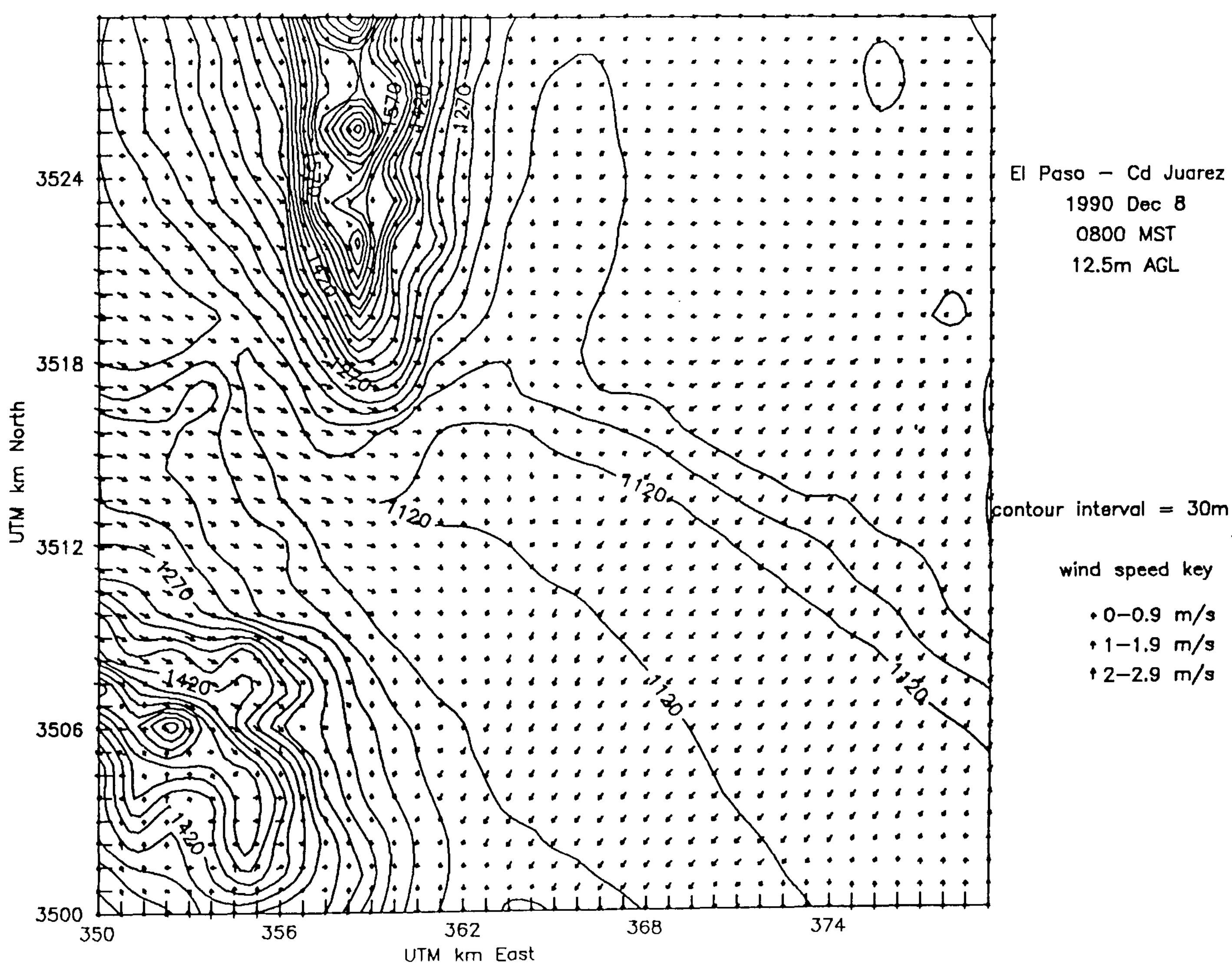
El Paso — Cd Juarez
1990 Dec 8
0800 MST
12.5m AGL
contour interval = 30m
wind speed key
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1–1.9 m/s
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UTM km North
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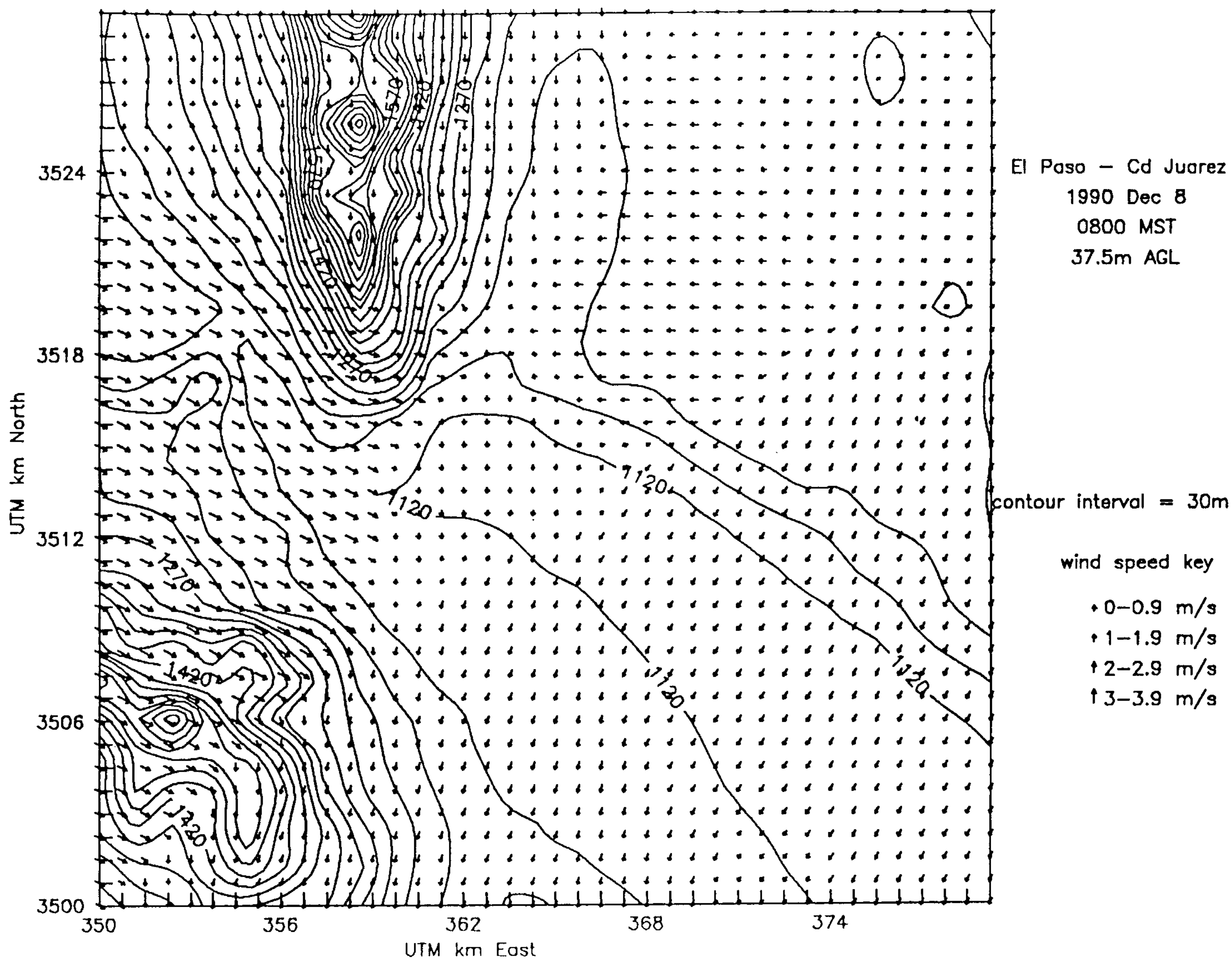

El Paso — Cd Juarez
1990 Dec 8
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wind speed key
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2–2.9 m/s
3–3.9 m/s
UTM km North
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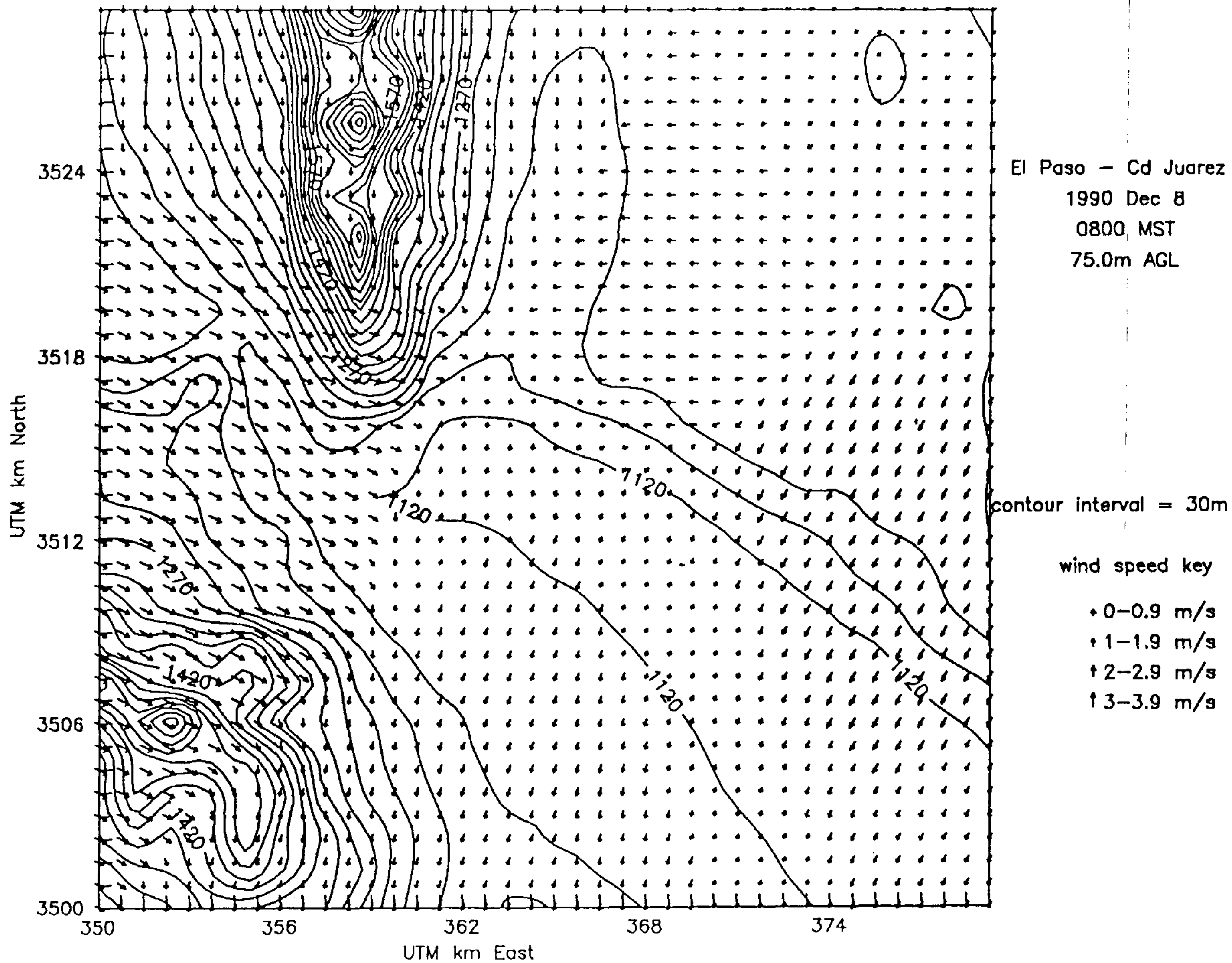
El Paso – Cd Juarez
1990 Dec 8
0800 MST
75.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
UTM km North
UTM km East
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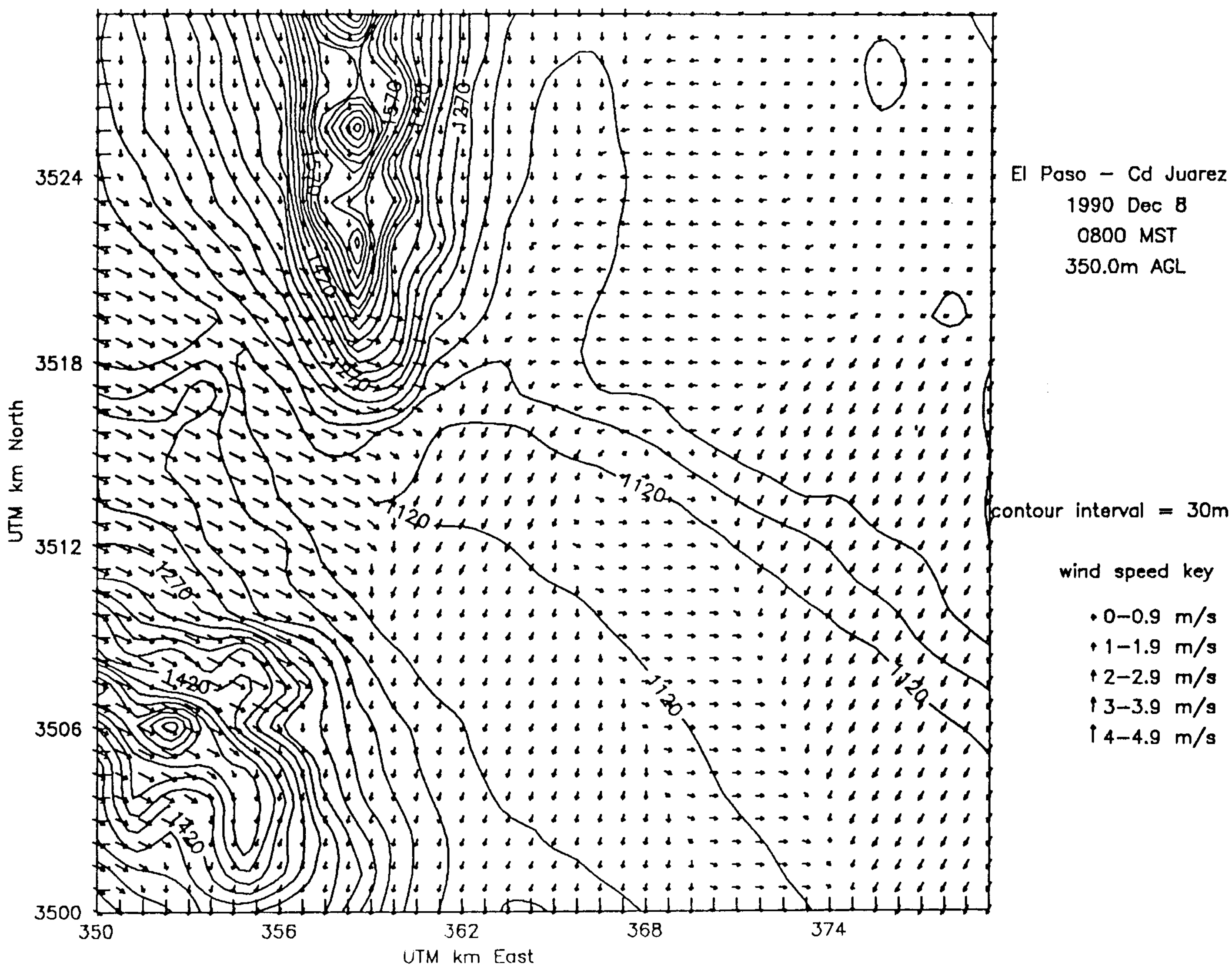

El Paso – Cd Juarez
1990 Dec 8
0800 MST
350.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
4–4.9 m/s
UTM km North
UTM km East
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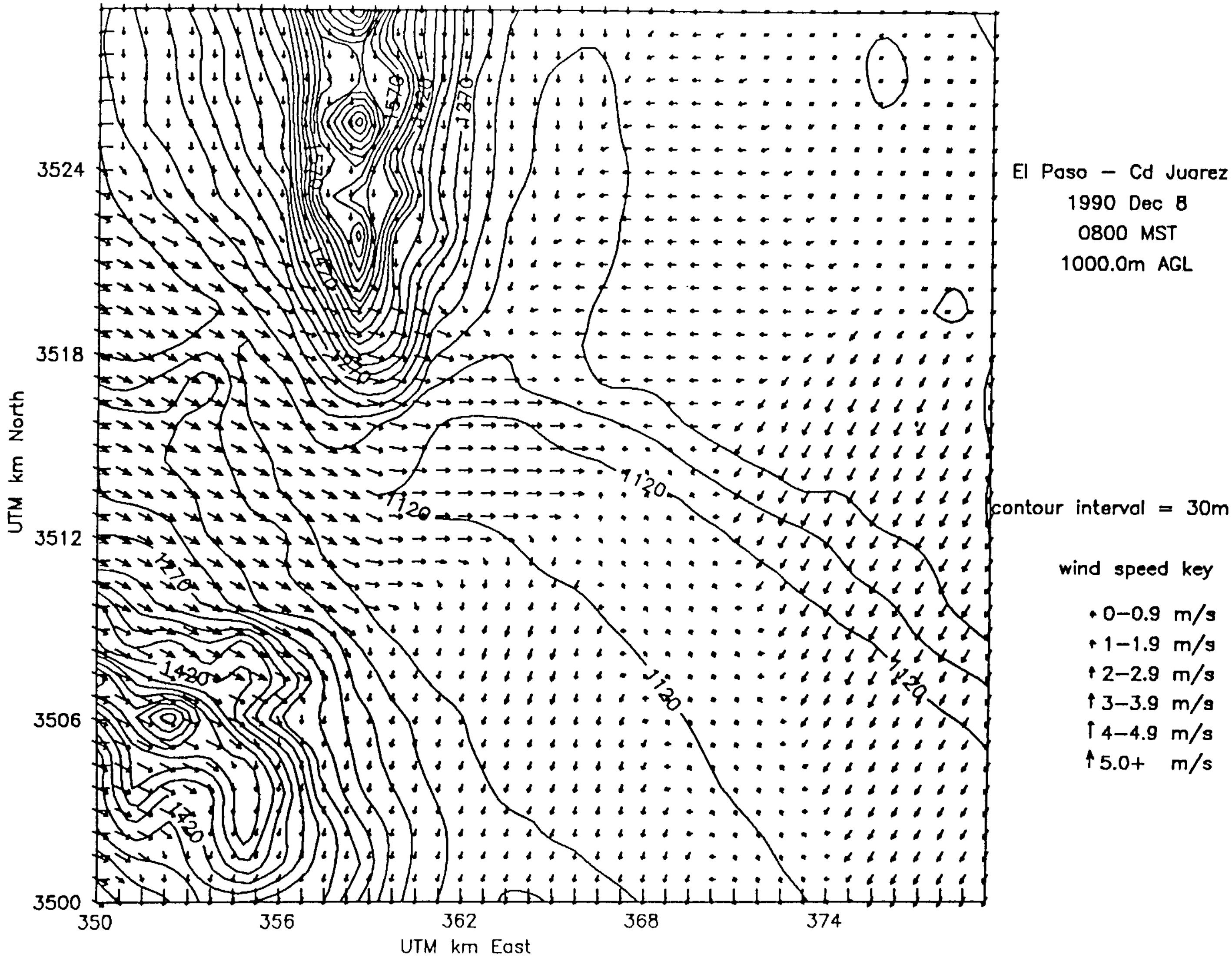
El Paso — Cd Juarez
1990 Dec 8
0800 MST
1000.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
4–4.9 m/s
5.0+ m/s
UTM km North
UTM km East
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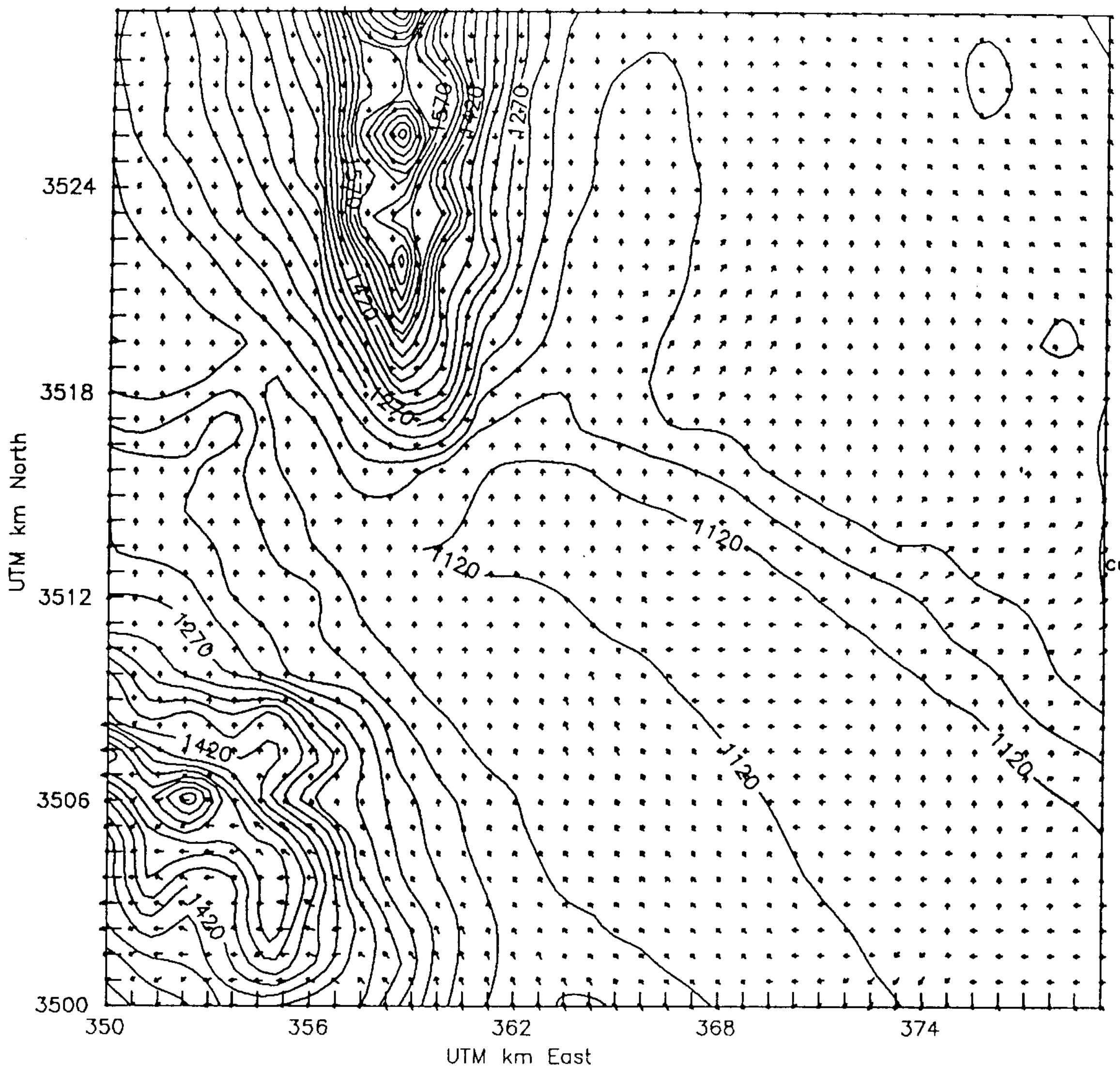
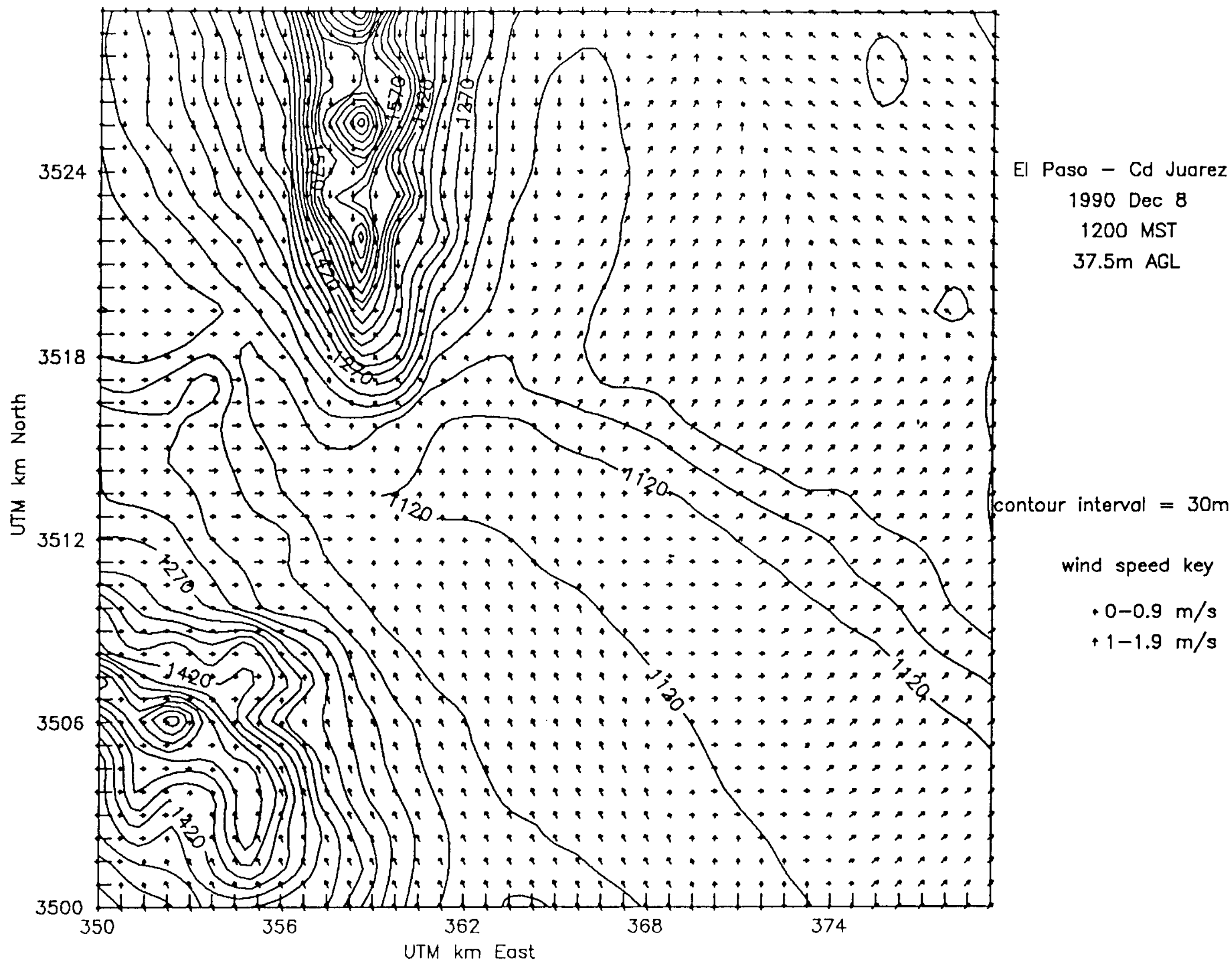


El Paso – Cd Juarez
1990 Dec 8
1200 MST
12.5m AGL

contour interval = 30m

wind speed key

0–0.9 m/s
1–1.9 m/s
2–2.9 m/s



El Paso – Cd Juarez
1990 Dec 8
1200 MST
37.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
UTM km North
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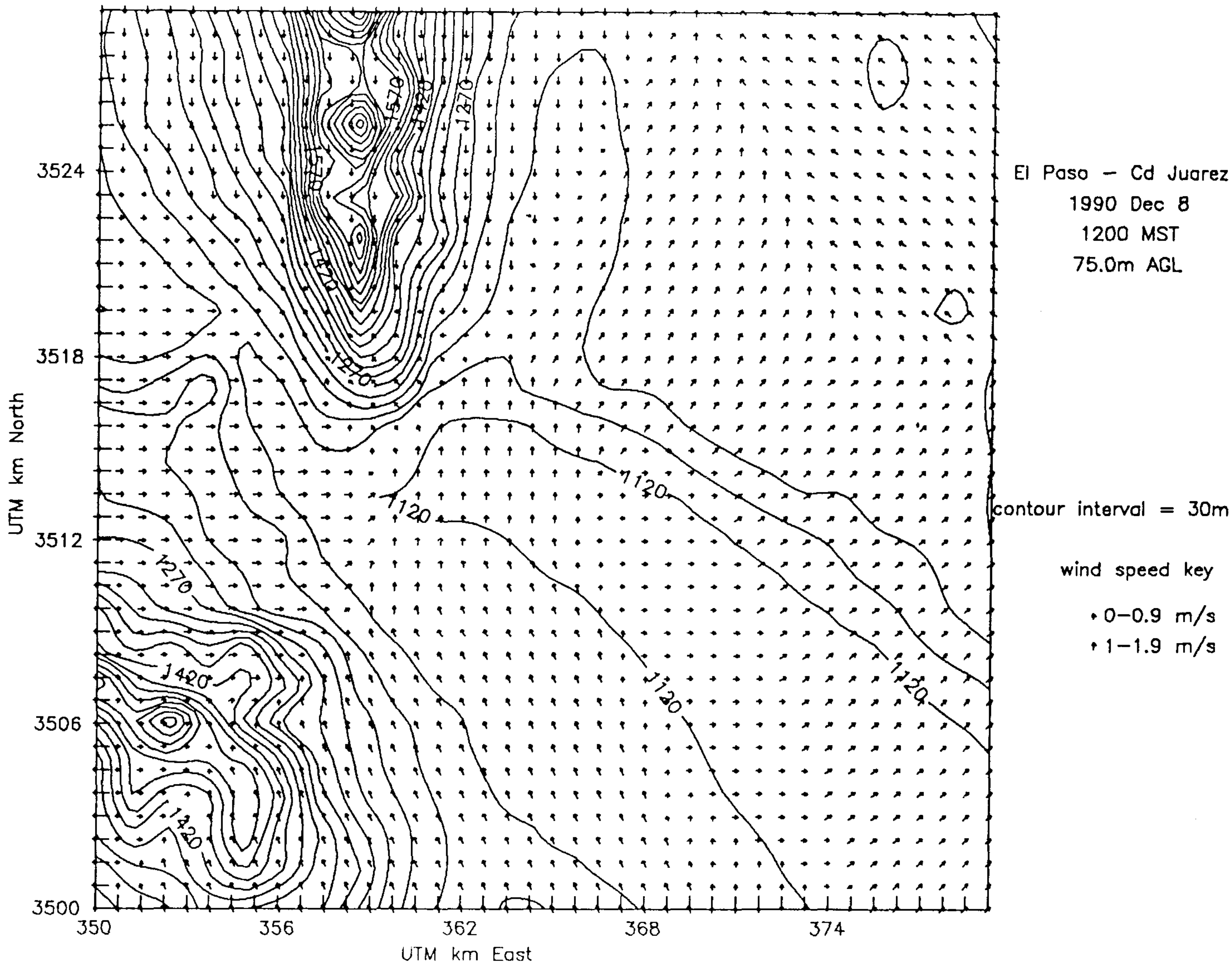

El Paso – Cd Juarez
1990 Dec 8
1200 MST
75.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
UTM km North
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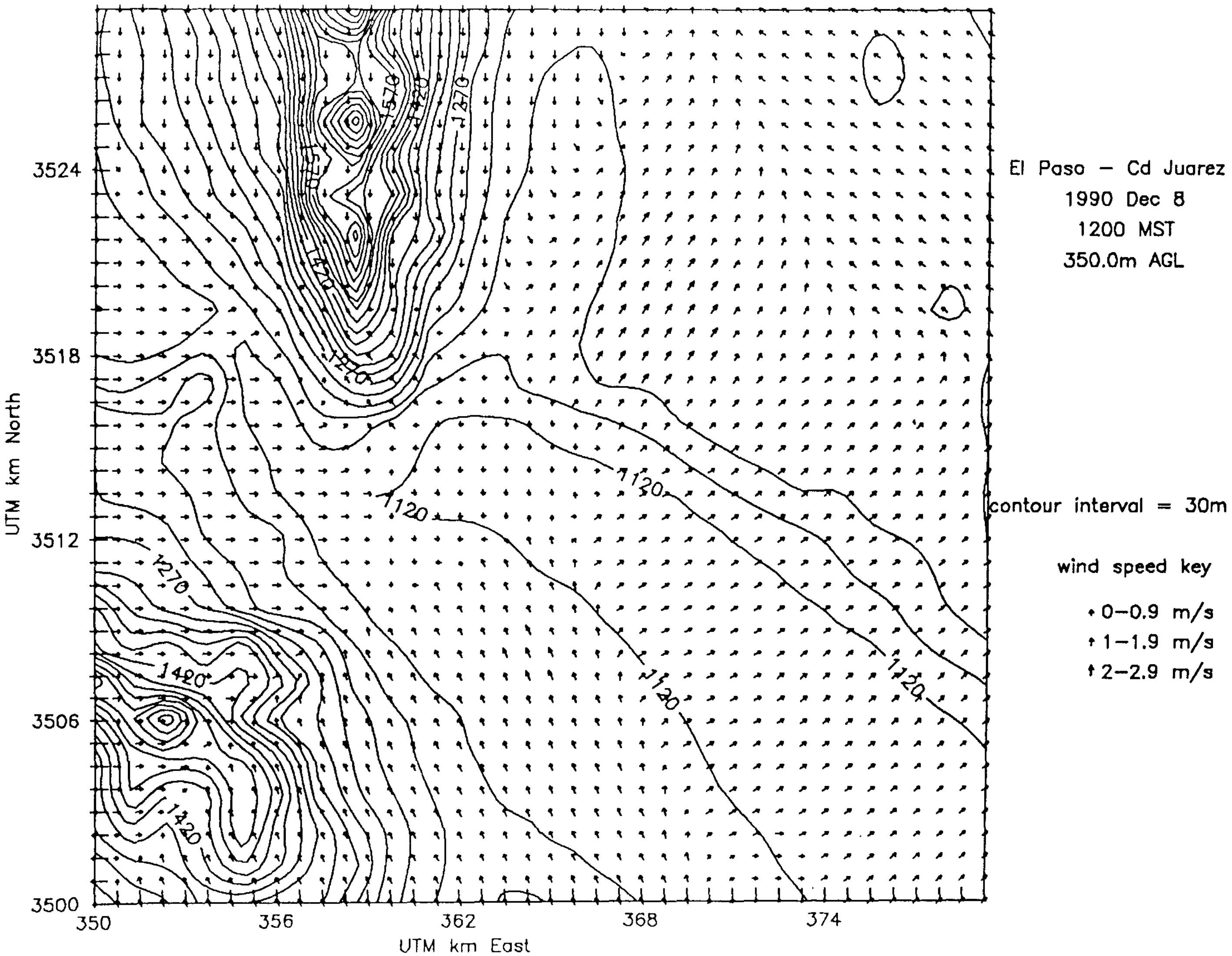
El Paso — Cd Juarez
1990 Dec 8
1200 MST
350.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
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2–2.9 m/s
UTM km North
UTM km East
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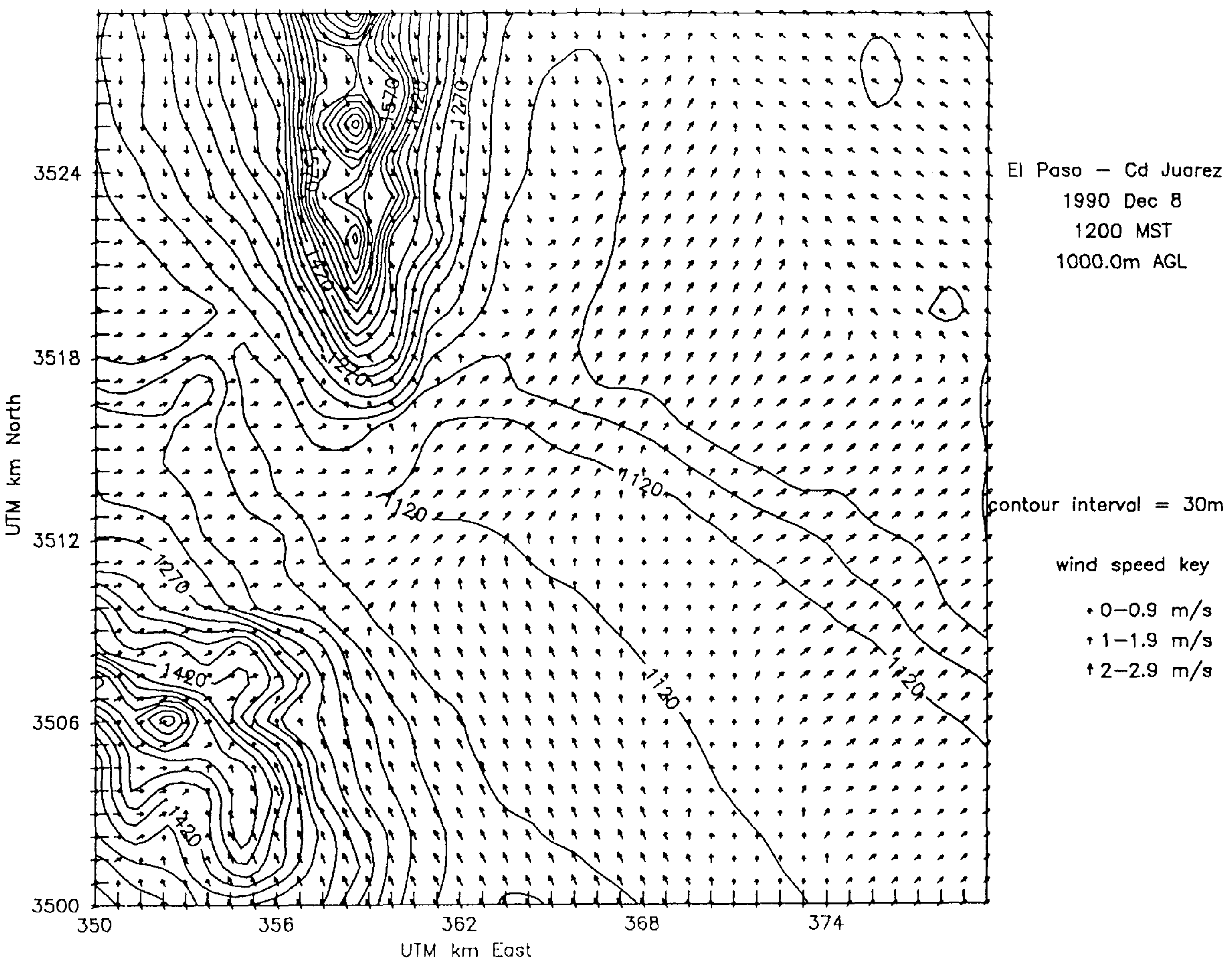

El Paso — Cd Juarez
1990 Dec 8
1200 MST
1000.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
UTM km East
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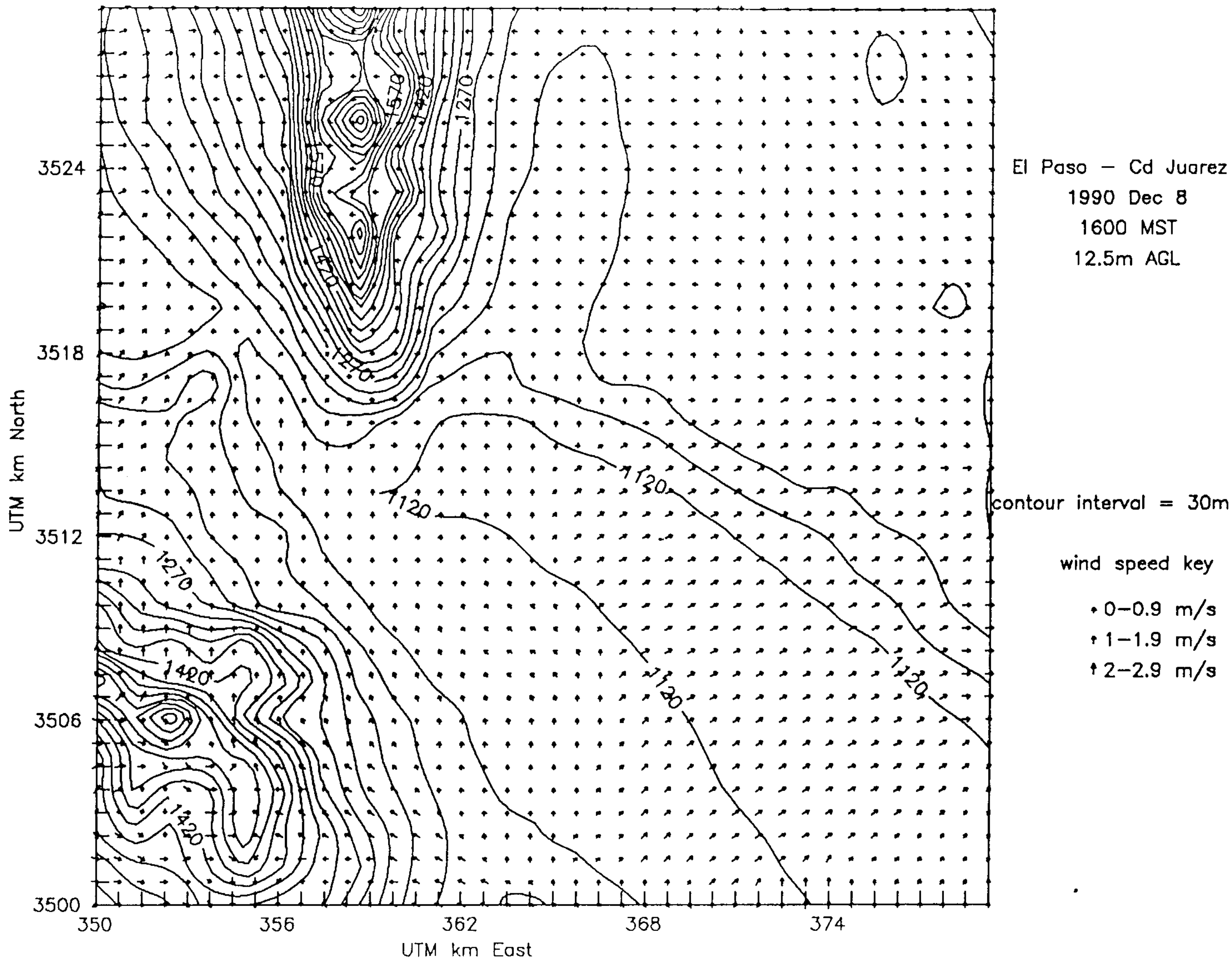
El Paso — Cd Juarez
1990 Dec 8
1600 MST
12.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
UTM km East
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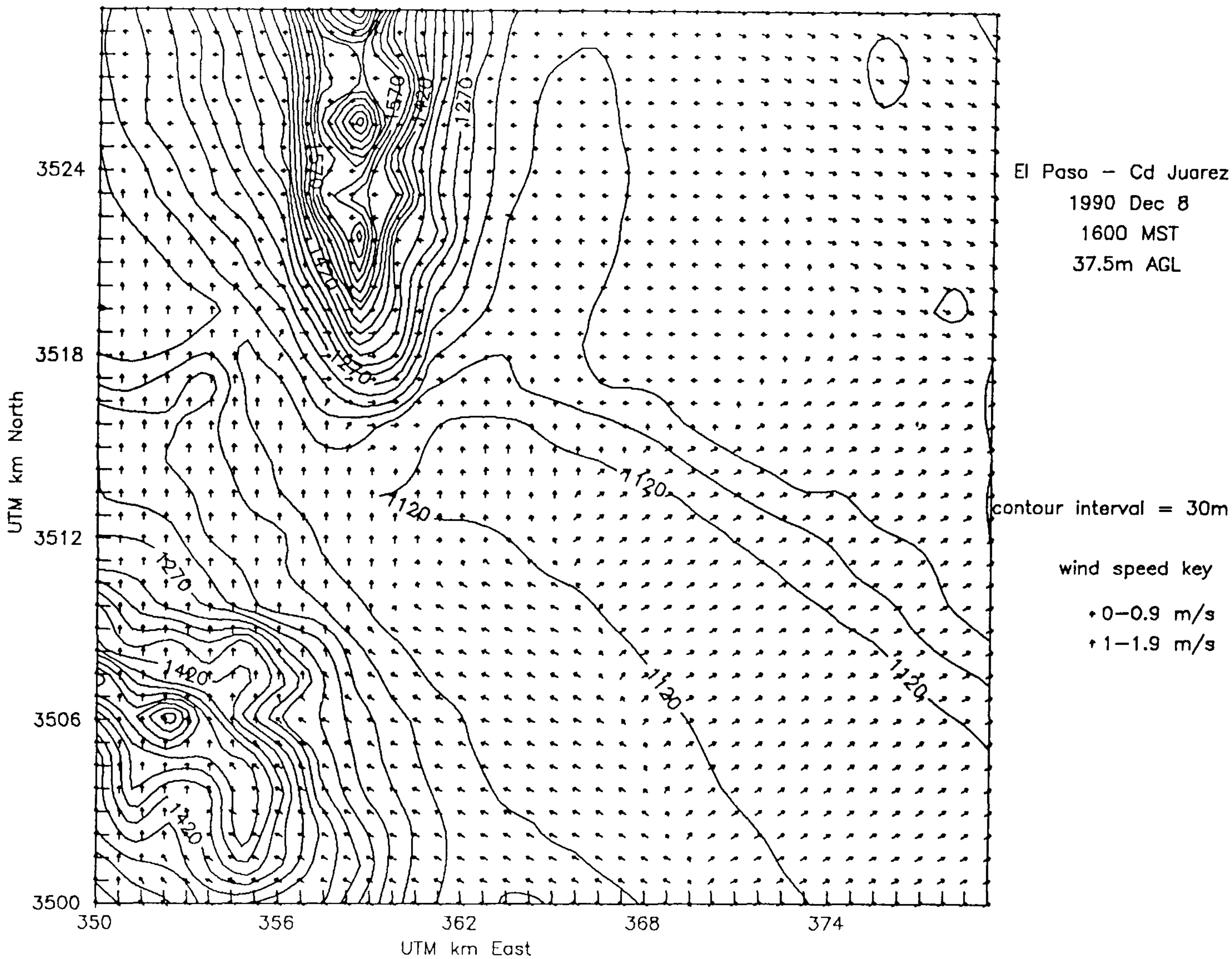

El Paso – Cd Juarez
1990 Dec 8
1600 MST
37.5m AGL
contour interval = 30m
wind speed key
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1–1.9 m/s
UTM km North
UTM km East
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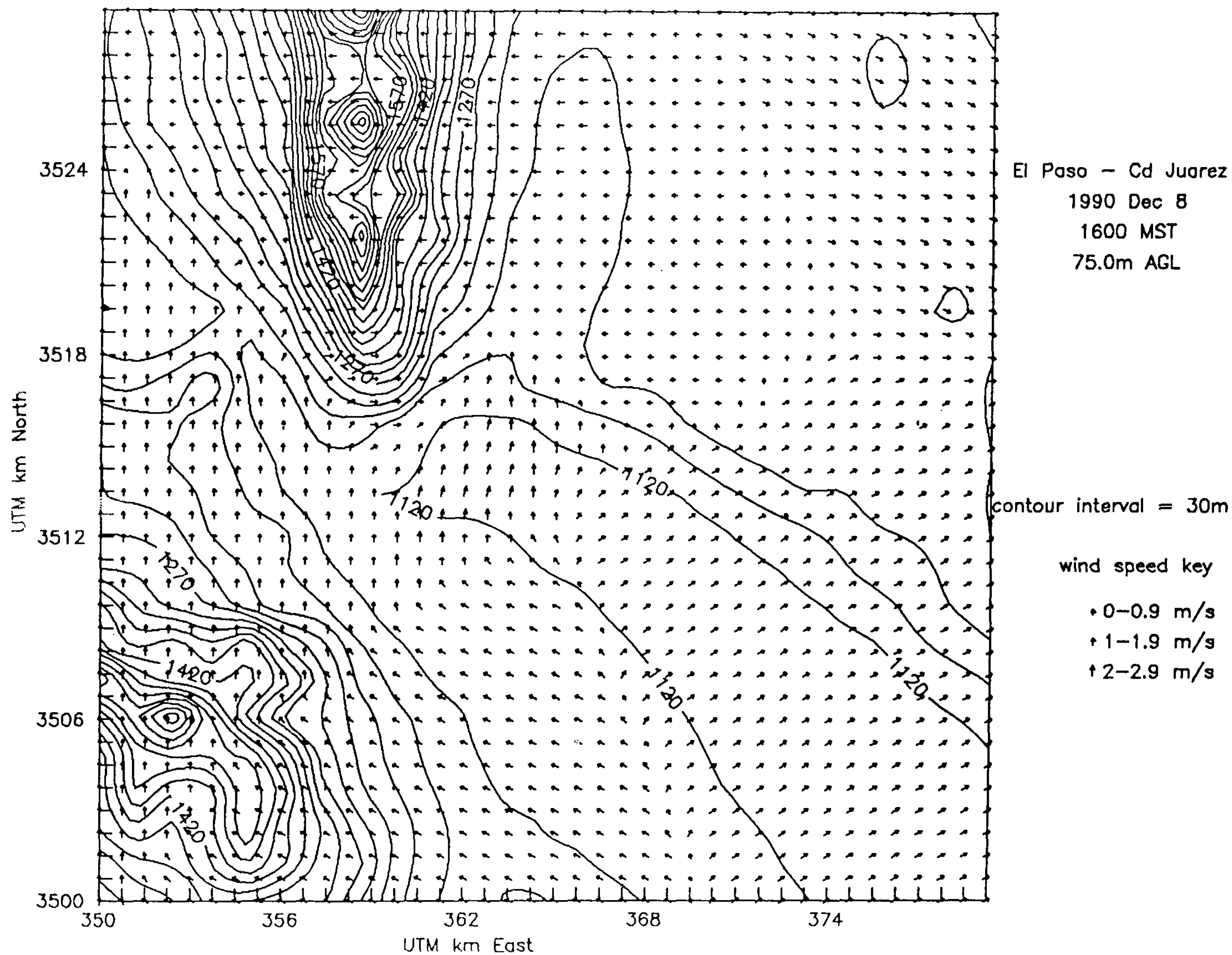

El Paso – Cd Juarez
1990 Dec 8
1600 MST
75.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
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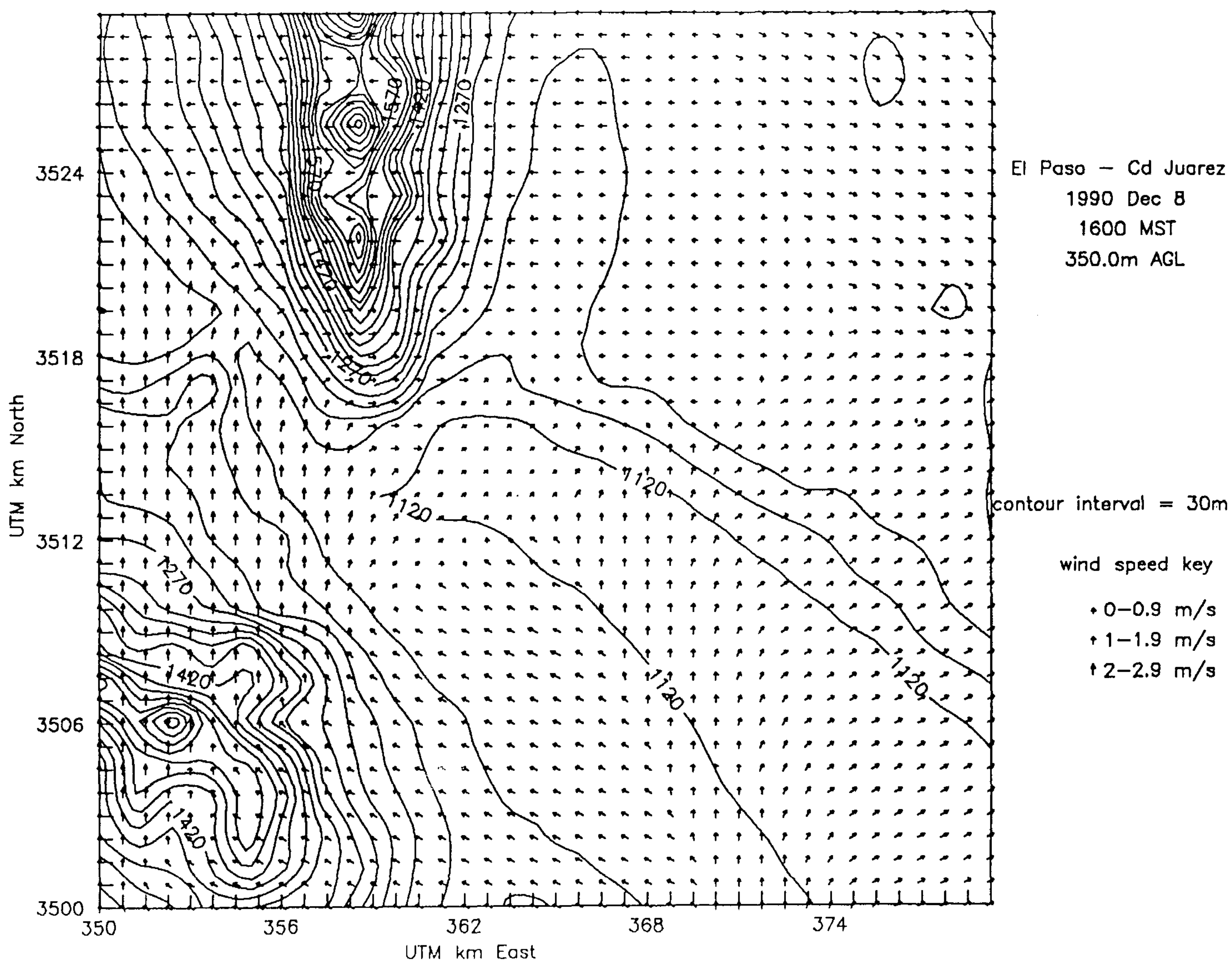

El Paso — Cd Juarez
1990 Dec 8
1600 MST
350.0m AGL
contour interval = 30m
wind speed key
0—0.9 m/s
1—1.9 m/s
2—2.9 m/s
UTM km North
UTM km East
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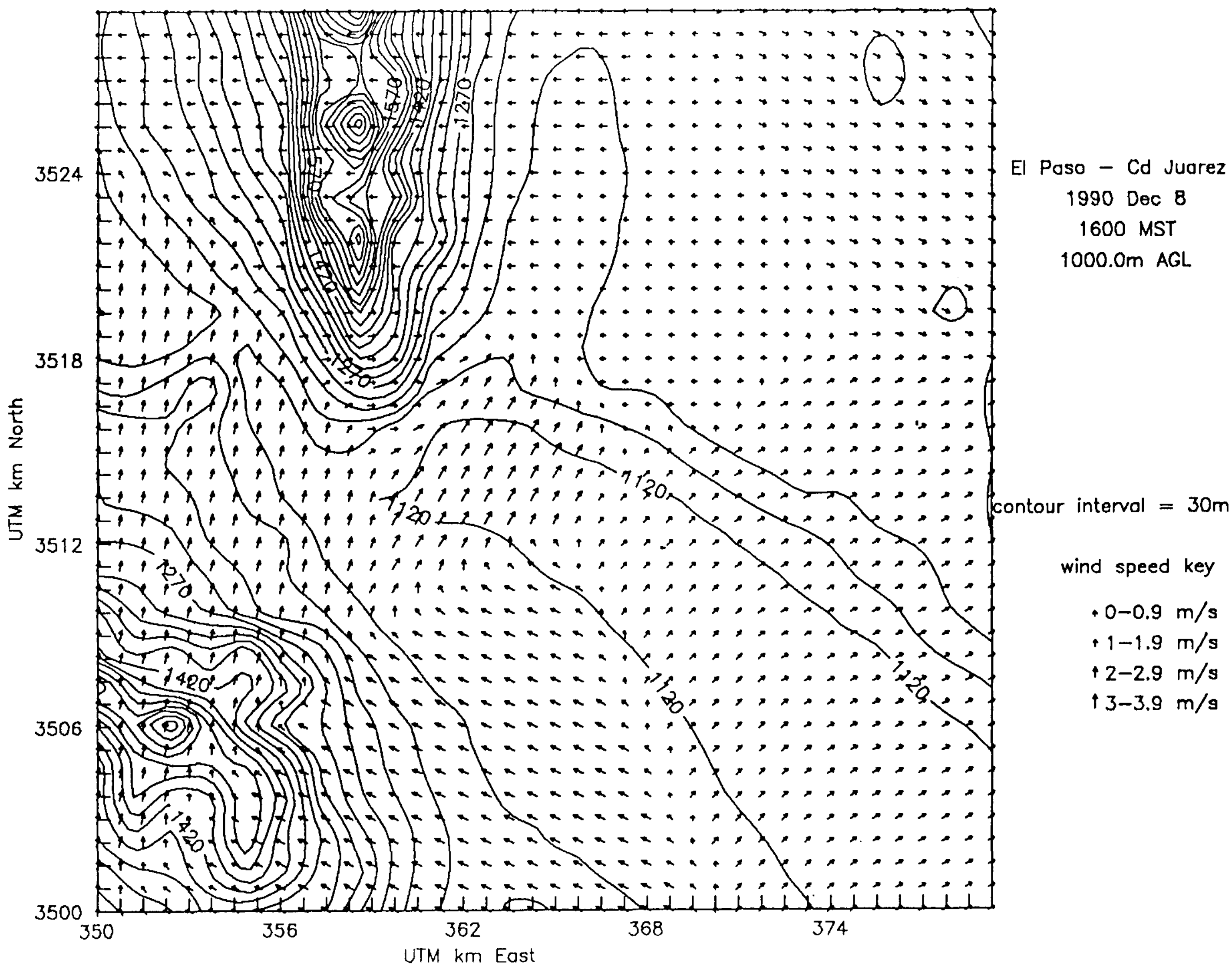
El Paso — Cd Juarez
1990 Dec 8
1600 MST
1000.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
UTM km North
UTM km East
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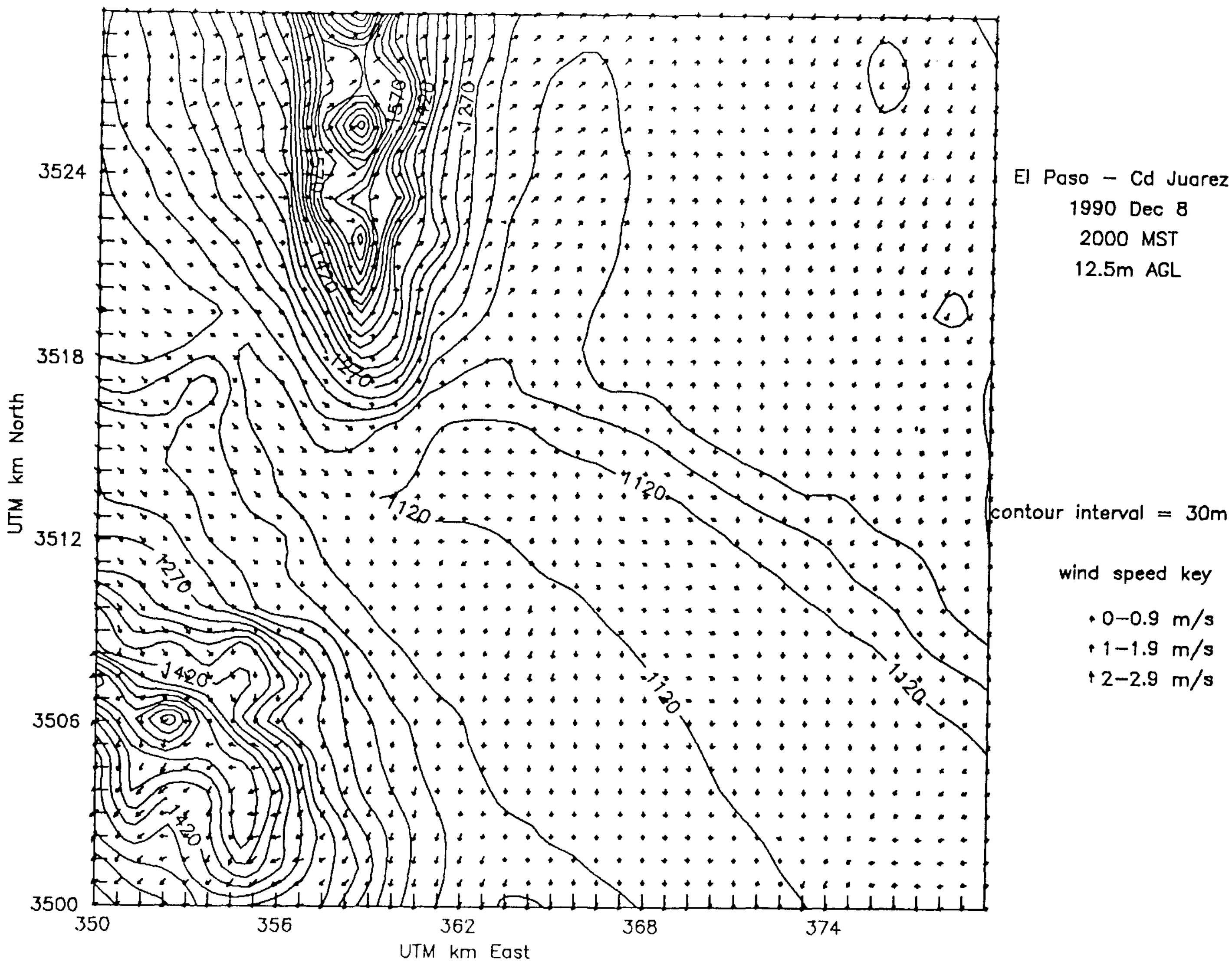
El Paso – Cd Juarez
1990 Dec 8
2000 MST
12.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
UTM km North
UTM km East
3500
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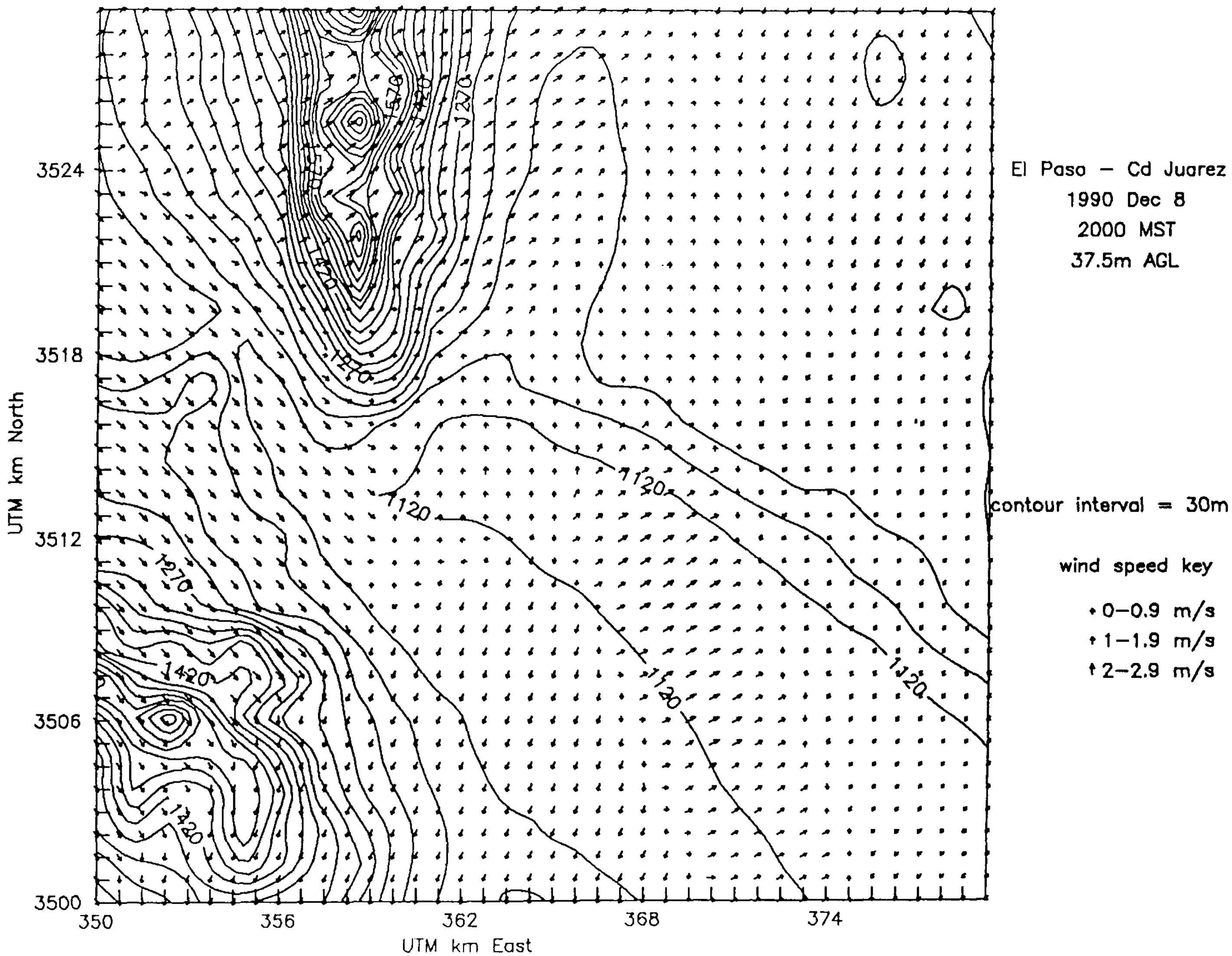
El Paso — Cd Juarez
1990 Dec 8
2000 MST
37.5m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
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2–2.9 m/s
UTM km North
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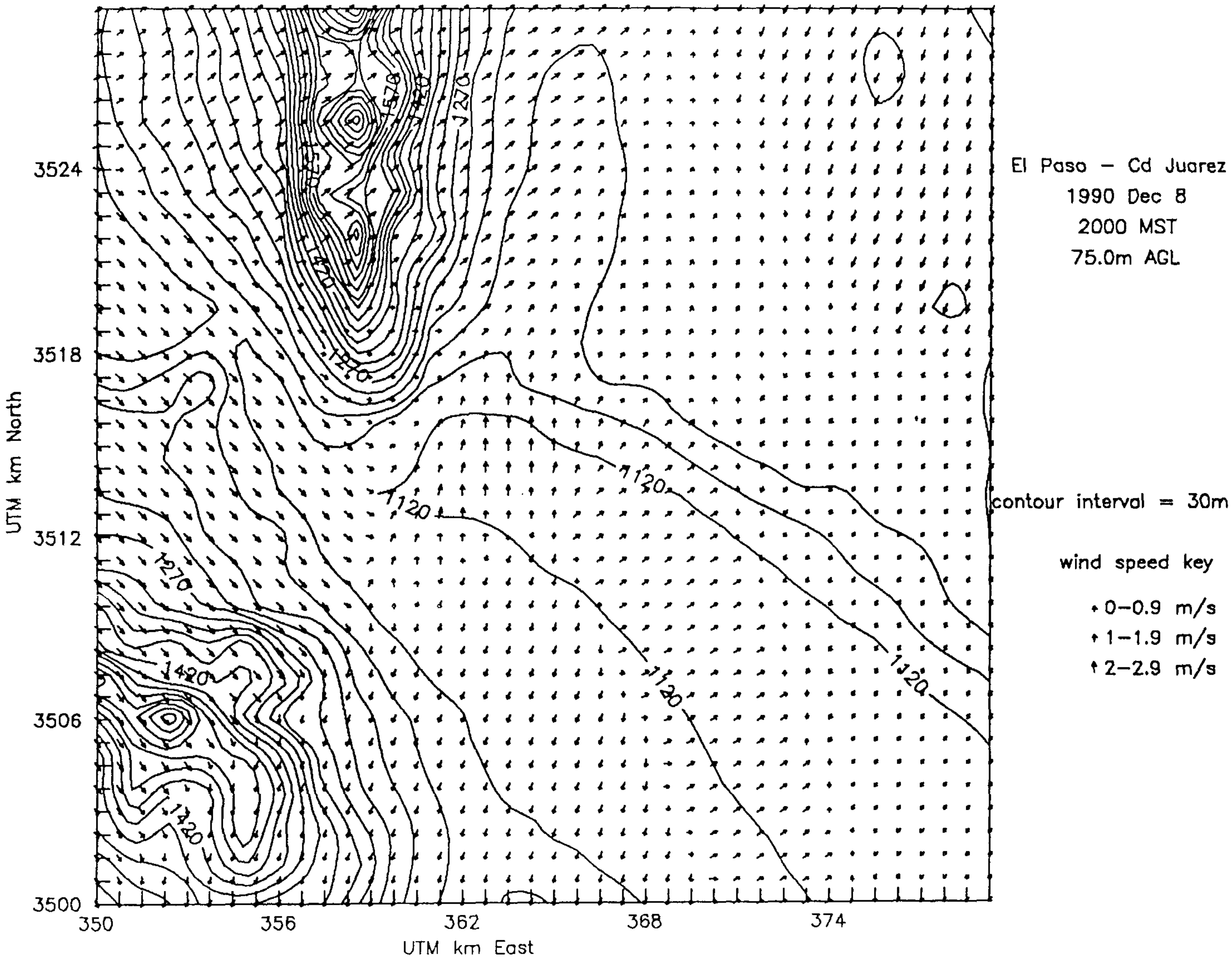
El Paso – Cd Juarez
1990 Dec 8
2000 MST
75.0m AGL
contour interval = 30m
wind speed key
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UTM km North
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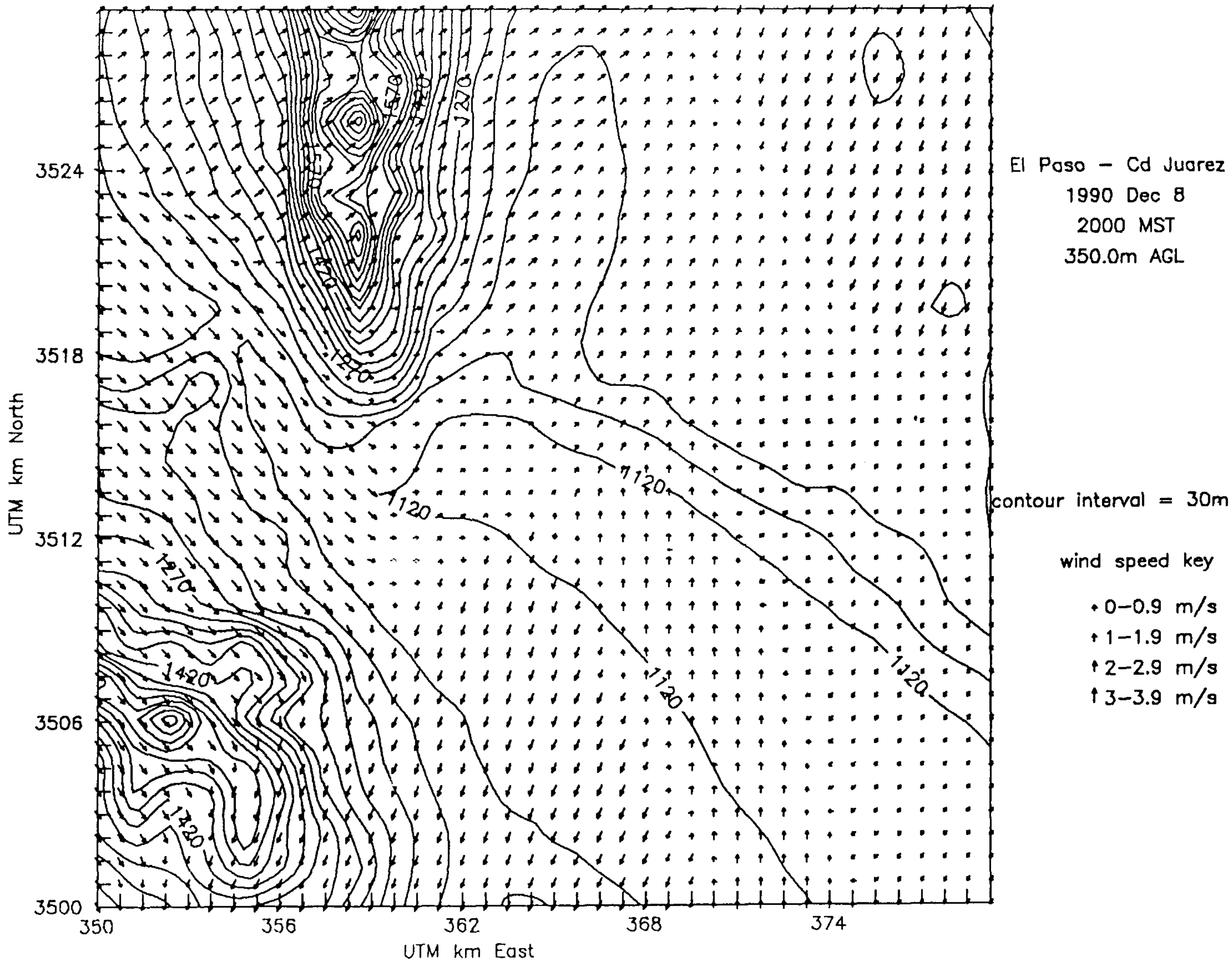

El Paso – Cd Juarez
1990 Dec 8
2000 MST
350.0m AGL
contour interval = 30m
wind speed key
0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s
UTM km North
UTM km East
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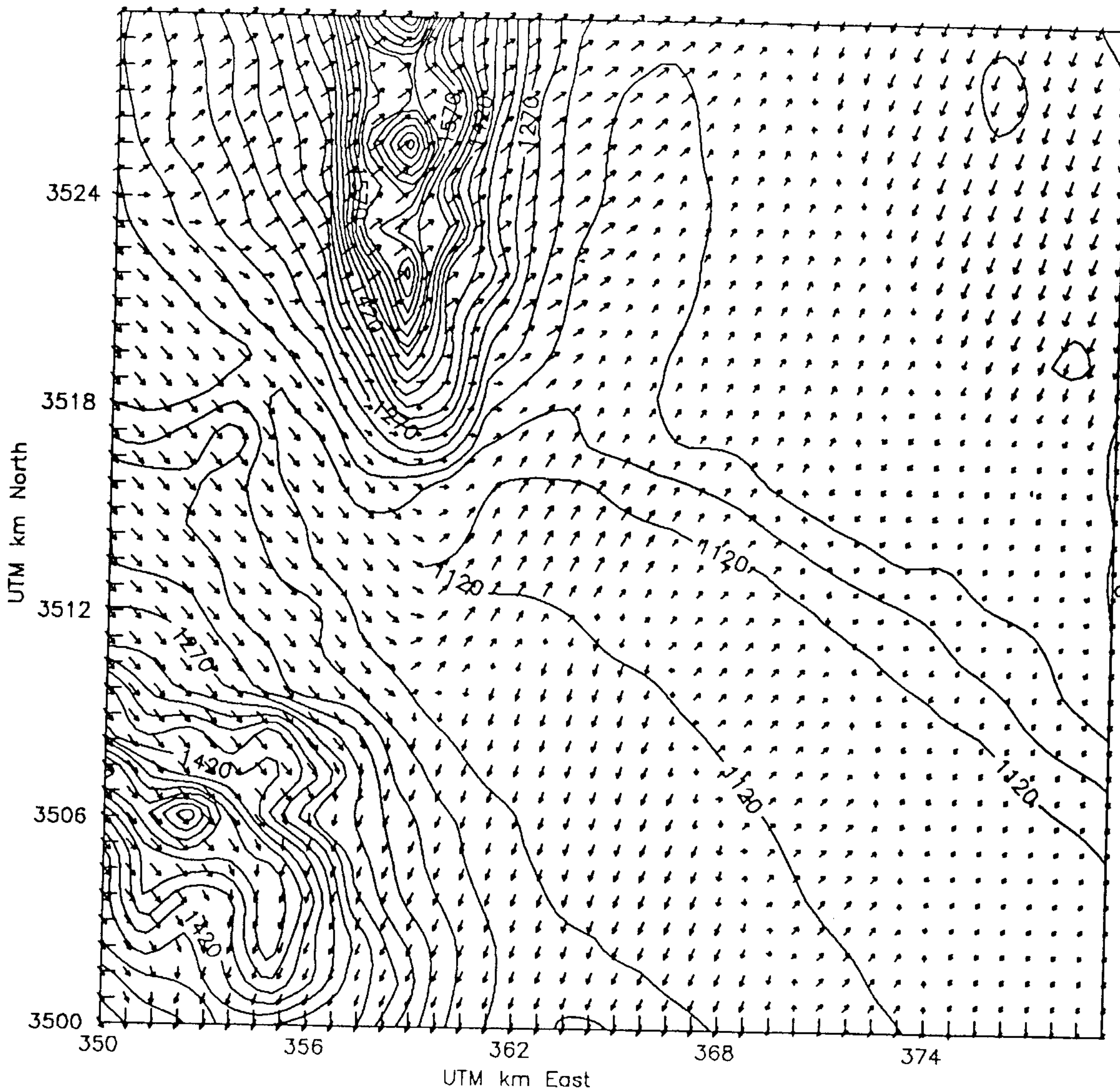

El Paso – Cd Juarez
1990 Dec 8
2000 MST
1000.0m AGL

contour interval = 30m

wind speed key

0–0.9 m/s
1–1.9 m/s
2–2.9 m/s
3–3.9 m/s

Distribution List

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New Mexico Environment Department
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J. Clayton Heskett
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PO BOX 1293
Albuquerque, NM 87103
Attention: Steve Walker

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