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The United Mexican States The Study on Air Pollution Control Plan in the Federal District Final Report October 1988

THE UNITED MEXICAN STATES

THE STUDY ON AIR POLLUTION CONTROL PLAN IN THE FEDERAL DISTRICT

FINAL REPORT

October 1988

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of the United Mexican States, the Japanese Government decided to conduct the Study on Air Pollution Control Plan in the Federal District and has entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Mexico a survey team headed by Dr. Akira UCHIDA of Pacific Consultants International Co., Ltd., comprising members of Pacific Consultants International Co., Ltd. and Research, Analysis & Computing Co., Ltd. from February to December 1987 and from May to June 1988.

The team held discussions with concerned officials of the Government of Mexico and the Department of Federal District, and conducted a field survey. After the team returned to Japan, further studies were made and the present report has prepared.

I hope that this report will serve for the development of the project and will contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the United Mexican States for their close cooperation extended to the team.

October, 1988

Kensuke Yanagiya
President
Japan International Cooperation Agency

SUMMARY

1. Introduction

1.1 Objectives of the Study

The Study aims to prepare a guideline for control measures against the air pollution problem in the Mexico City Metropolitan Area (AMCM) based on the findings of on-site investigations in Mexico City and analyses in Japan. Technology transfer from the Japanese side to the Mexican counterpart was also intended in the course of the Study.

1.2 Outline of the Study

Outline of the Study is shown in Figure 1 as a general work flow. Almost all of air pollutant source control measures that are considered effective for the air pollution of AMCM are already planned by the Mexican Government and some of these measures are already being executed. Therefore, in preparation of a guideline for air pollution control measures, emphasis was placed on estimation and evaluation of effects of the source control measures adopted by the Government.

1.3 Study Area

Federal District and seventeen cities (municipios) in the State of Mexico compose the Mexico City Metropolitan Area. As shown in Figure 2, this Study covered a large part of AMCM where air pollution is significant.

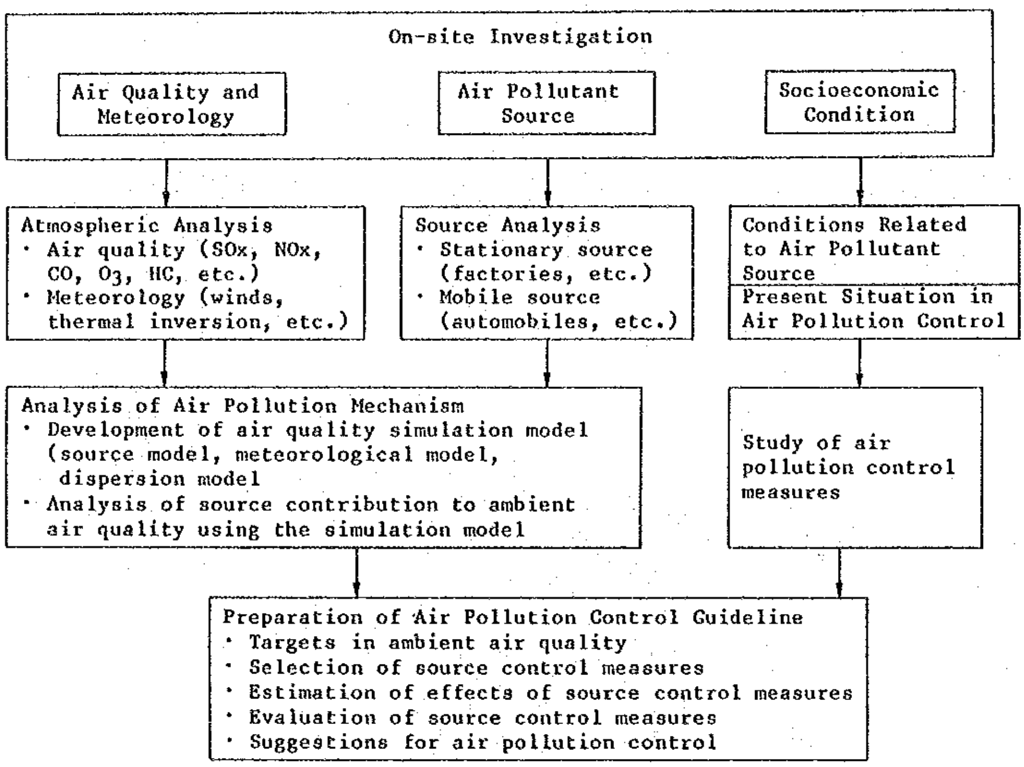


Figure 1 General Work flow for the Study

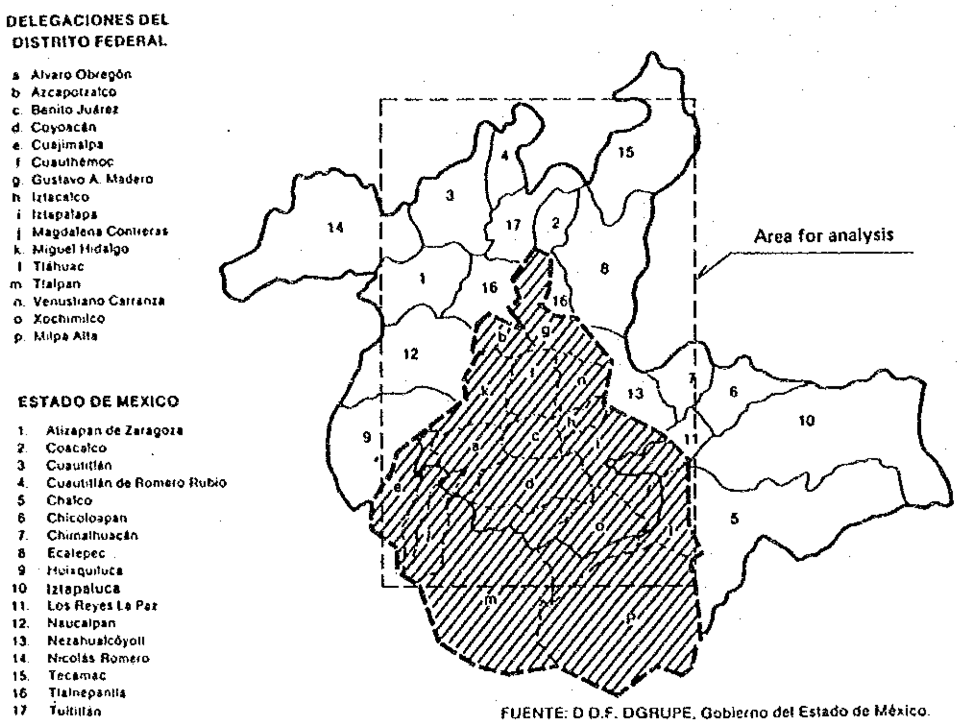


Figure 2 Study Area

2. General Description of the Study Area

The Mexico City Metropolitan Area is located in the Valley of Mexico which is surrounded by the mountain ranges except for the north direction. The altitude of the bottom of the valley is about 2200m, and the surrounding mountains are higher than 3000 m. The region enjoys a warm and dry climate. The annual average temperature is about 15°C. Monthly average temperature is highest in May at 17.4°C and lowest in January at 12.1°C. Annual precipitation is 725 mm, most of which occurring in the period from June to September.

The population of AMCM was about 18 millions in 1986, of which about 10 millions are in the Federal District (DF) and 8 millions in the 17 municipios of the State of Mexico. The total population is more than three times that of 1960, and the growth of the population is more significant in the areas of the Mexico State in the recent years. A population forecast for the year 2000 gives a total of 27.3 millions for AMCM of which 12.7 millions are for DF and 14.6 millions for the Mexico State area.

The northern part of DF and its adjacent zones to the north in the State of Mexico are highly urbanized, and many industrial zones are also located in this part of AMCM.

Major types of manufacturing industries are chemicals, steel, metallic products, foods, ceramics and papers.

Among traffic means, urban and suburban buses account for 42% of all passengers, followed by taxis (20%), subways (18%), passenger cars (18%) and trolley buses and light trains (3% in combined). There are about 3 million vehicles in AMCM including 2.35 million passenger cars which occupy 78% of the total.

Fuels used in AMCM are mostly petroleum liquid fuels and natural gas. There are two thermoelectric power generation plants in AMCM which supply about 25% of the total demand of the region. The rest is supplied by hydroelectric power plants located outside the Mexico Valley.

3. Present State of Air Pollution

A phenomenon of air pollution can be conceptualized as shown below in terms of its causes, influential factors and results.

(Causes)
Quantity of air pollutants discharged into the environment
- types of pollutant
- spatial distribution
- temporal variation
- method of discharge

(Influential Factors)
- Meteorological condition (winds, temperature, etc.)
  - spatial variation
  - temporal variation
- Geography
- Topography

↓

(Results)
Ambient air quality (pollutant concentration)
- types of pollutant
- spatial distribution
- temporal variation

The contents of investigations on the three components shown above and the resultant findings on the existing state of air pollution in Mexico City are described below.

3.1 Contents of Investigation

(1) Meteorology and Ambient Air Quality

Contents of investigations made on meteorology and ambient air quality are summarized in Table 1 and Table 2, respectively.

(2) Air Pollutant Source

Investigations of air pollutant sources were made for mobile and stationary sources to estimate quantity of pollutants emitted from each type of source as shown in Table 3 and Table 4.

Table 1 Investigation of Meteorology

Category		Item	Height from the ground	Site	Period	Major purpose
On-site observation	Ground level	WD/WS Turbulence	15 m	Vehicle exhaust gas diagnostic center No.5, DDF	Sept. 1987 - May 1988	Reference for diffusion parameters in air quality simulation
	Upper level (captive sonde)	WD/WS Temperature	Up to 500m at every 50m		Sept. 1987 (5 days) Nov.-Dec. 1987 (14 days) Feb. 1988 (7 days) May 1988 (7 days)	Analysis of vertical profiles of temperature and WD/WS. Analysis of trend of occurrence of thermal inversion. Vertical division of meteorological blocks for air quality simulation model.
	Upper level (low-level sonde)	Temperature	Up to 1500m at every 50m			
Collection of existing data	Ground level	WD/WS		TACUBAYA observatory	Jan.-Dec. 1986	Supplement to the on-site SEDUE stations
	Upper level	WD/WS Temperature	Up to 5000m	AEROPUERTO observatory	Jan.-Dec. 1986	Supplement to the data of observation
	Ground level	WD/WS		SEDUE's 10 air quality monitoring stations	Dec. 1986 - Nov. 1987	Analysis of regional characteristics of WD/WS. Horizontal division of meteorological blocks for air quality simulation model

WD/WS: Wind direction and wind speed

Table 2 Investigation of Ambient Air Quality

Category		Item	Site	Period and frequency	Major purpose
On-site measurement	Long-term measurement at fixed stations	NO, NO_2, NOx	Central office of DDF	Sept. 1987 - Aug. 1988 Continuous	Supplement to SEDUE's measurement at 5 stations
		TPS by particle size. Metallic elements in TSP by particle size.	5 points in and around DF	Sept. 1987 - Aug. 1988 Monthly, 3 days per month	Analysis of source contribution to TSP
	Measurement using monitoring vehicles	SO_2, NO, NO_2, NOx, CO, SPM, NMHC, O_3, WD/WS	19 points in road-side and off-road areas in and around DF	Dec. 1987 - Sept. 1988 One month per point, Two vehicles	Short-term variation of pollutant concentration. Influence of automobiles to air quality.
	Measurement by simplified method	NO_2, NOx	12 major road crossings in DF. 50 points/crossing.	Oct. 1987 - June 1988 2-3 crossings/month, 2-3 times/crossing, 48 hours/time	Concentration distribution of NOx at roadside area
Collection of existing data for long-term continuous measurement		SO_2, NO_2, CO, O_3, HC	SEDUE's 25 stations for continuous air quality monitoring in AMCM	Dec. 1986 - Nov. 1987 Continuous	Evaluation of regional ambient air quality throughout a year. Development of air quality simulation model.

Table 3 Investigation of Mobile Sources of Air Pollutants

Category		Name of investigation or data	Major purpose
Automobile traffic volume	Existing data	Traffic volume survey by DDF (1986)	Traffic volume in major roads. Type distribution. Time variation.
		Traffic volume survey by Mexico State 1985)	
		Noise/traffic survey by DDF (1984)	
	On-site investigation	Traffic volume survey (1987)	
		Traffic volume reading on aerophotographs (1987)	Traffic volume in secondary roads
Driving speed	On-site investigation	Field driving test (1987)	Driving speed by type of road
Emission factor		Chassis dynamometer test (1987)	Emission factors by type of passenger car
	Existing data	Study by Tokyo Metropolitan Gov. (1978)	Emission factors for bus
		Chassis dynamometer test for light diesel vehicles at high altitude, APCA (1983)	Altitude compensation of emission factors
Number of automobiles		Automobile registration records at four delegaciones in DF (1986)	Number of automobiles and type distribution
		Automobile sales record in Mexico (1970 - 1986)	
Aircrafts	Existing data	Number of takeoff and landing at Benito Juarez Airport (1986)	Aircraft flight volume
		Manual for total control of NOx emissions, Environment Agency, Japan (1982)	Emission factors for aircraft

Table 4 Investigation of Stationary Sources of Air Pollutants

Category	Name of investigation	Major purpose
Large sources	Questionnaire in written form and on site for 460 factories in AMCM, DDF/JICA (1987)	Quantity, location and height of pollutant emissions
Small sources	Questionnaire in written form for 4739 service and commercial establishments in DF, DDF (1988)	Quantity of pollutant emissions by delegacion
Sulfur content of fuels	Measurement of sulfur content of heavy oil and diesel at 6 factories, JICA (1987)	Confirmation of existing data for sulfur content
Pollutant emissions	Measurement of emission of SO_2, NOx, and smoke and soot at 20 factories, JICA (1987)	Confirmation of results of the factory questionnaire

(3) Air Quality Simulation

Major purposes of air quality simulation conducted in this Study are as follows.

a. To express quantitatively the relationship between prevailing ambient air quality and its causes and influential factors thereby enabling estimation of source contributions

b. To estimate effects of pollutant source control measures on the ambient air quality

The air quality simulation model employed in this Study consists of a source model, a meteorological model and a dispersion model. The dispersion model includes several dispersion equations each of which is applied under specific conditions of source and meteorology. The basic equation in the dispersion model applied to point sources at windy conditions is a plume equation proposed by Holland in 1953 which is written as follows.

$$C(x,z) = \frac{Q}{\sqrt{2\pi}\,\frac{\pi}{8}\,x\,\sigma_z\,U}\left[\exp\left(-\frac{(z-He)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+He)^2}{2\sigma_z^2}\right)\right]$$

where, C : concentration of a pollutant (ppm)

x : downwind distance from the source (m)

z : height of the point from the ground where the concentration is to be computed (m)

Q : pollutant emission rate (m^3/s)

σ_z : vertical diffusion parameter evaluated in terms of downwind distance x (m)

U : wind speed (m/s)

He: effective stack height (m)

3.2 Ambient Air Quality

(1) General Level of Pollutant Concentration

When the annual measurement result for each pollutant is compared with the ambient air quality standard value, the following can be said.

The concentration of NO_2, SO_2 and CO generally satisfies the air quality standard except that of SO_2 and CO at a few localities.

The concentration of O_3 exceeds the standard level for 3% to 65% of the days of the year, the percentage depending on locality.

The concentration of HC exceeds the recommended level for 30% to 70% of the days of the year.

When the pollutant concentration levels are compared with those in Japan for reference, SO_2, CO, HC, SPM (suspended particulate matter) and O_3 are higher in Mexico City, and NO and NO_2 are at the similar levels.

(2) Hourly Variation

a. Two-peak pattern

Hourly variation of the concentration of SO_2, NO, NO_2, CO and HC shows a two-peak patttern: the first peak at 8:00 a.m. to 10:00 a.m., and the second peak at 8:00 p.m. to 10:00p.m.

b. One-peak pattern

Hourly variation of the O_3 concentration shows one peak at noon to 3:00 p.m.

c. Other pattern

Hourly variation of SPM shows a peak in the morning hours and rises again in the afternoon to a certain level but without a definite peak.

(3) Seasonal Variation

Characteristics of seasonal average concentration of the pollutants are as follows.

a. Pollutants whose concentration is higher in winter than in summer are SO_2, NO, NO_2, CO, HC, and SPM.

b. The concentration of O_3 is higher in summer than in winter.

3.3 Meteorological Characteristics

Meteorological characteristics in Mexico City can be summarized as follows.

(1) Winds

a. Wind speed is generally low. Consequently, the air in the Mexico Valley is not easily replaced.

b. The wind system around Mexico City is mostly influenced by the local topographic conditions, and the winds are mostly of mountain-valley breezes. Influence of the seasonal geostrophic air currents is very small as indicated by the small atmospheric pressure gradient.

c. Wind speed is lower in the dry season (winter) than in the wet season (summer). In a day, winds are low during daytime and night, and highest at around 6:00 p.m.

d. Wind speed profile from the ground level to the height of 500m is almost uniform.

(2) Rain

Precipitation is small particularly in the dry season and virtually no effects of washout and rainout are expected in this season.

(3) Thermal Inversion

Characteristics of the thermal inversion observed in Mexico City are as follows.

a. Thermal inversion occurs frequently in the dry season. Inversion layers are formed most frequently at the height between 200 m and 500 m.

b. The inversion often appears at night and sustains until about 10:30 a.m., then begins disappearing with increasing amount of solar radiation.

c. Maximum mixing depth is about 200 m throughout the year. This height is similar to that observed in Japan during the summer.

(4) Conditions for Pollutant Dispersion

Since the wind speed is low, the degree of transport and dispersion of pollutants is generally low. Stable thermal stratification in the atmosphere during the night prevents dispersion of pollutants. But during the daytime, the increasing solar radiation brings about unstability of the air creating convective air currents which transport pollutants upward.

3.4 Pollutant Source Characteristics

(1) Stationary Sources

a. Although efforts have been made to increase the supply of natural gas, a large amount of heavy oils with the sulfur content more than 3% are still used as fuel. These heavy oils constitute a large portion of origins of SO_2.

b. Because of small height of stacks, pollutants are discharged below the thermal inversion layer.

c. Large-scale factories exist mostly in the northern areas, where increase in population is also signification in recent years. Consequently, industrial zones and residential zones exist adjacent to each others.

(2) Automobiles

a. There exist a considerable number of poorly maintained automobiles such as those with an ill-tuned engine.

b. Incomplete combustion of engine fuels due to the high altitude of the Mexico Valley and the poor engine maintenance causes high levels of CO and HC emissions.

c. Sulfur contained in the gasoline is considerably affecting the SO_2 concentration in certain areas along major roads.

3.5 Mechanism of Occurrence of High Pollutant Concentration

A high level of air pollution tends to occur in Mexico City during the dry season: from December to February. The major factors affecting the occurrence of high pollutant concentration are considered to be low wind speed, occurrence of thermal inversion, and little precipitation.

Figure 3 shows the hourly variation of the wind speed, the height of thermal inversion, and the ambient concentration of pollutants observed on February 22, 1988.

At around 8:00 a.m. to 10:00 a.m., a distinct inversion layer persisted at the height between 100 m to 300 m, and the levels of the pollutant concentration were considerably high. The inversion layer disappeared at about 11:00 a.m. with the increased solar radiation causing instability of the air and active dispersion of pollutants resulting in the decrease of the concentration of SO_2, NO, NO_2, HC and CO.

However, the concentration peak for O_3 occurred around noon about two hours later than the other pollutants indicating the time required for the reactions involving NO, NO_2 and HC to produce photochemical oxidants.

Then, the wind speed increased and it was maintained at high levels between 3:00 p.m. to 7:00 p.m., and the pollutant concentration levels decreased temporarily. But the concentration of the pollutants that are primarily originated from automobiles such as NO, CO and HC increased again from about 7:00 p.m. with the decreasing wind speed.

The pattern of occurrence of high pollutant concentration described above is considered to be typical of the Mexico Valley, although it is not always the case.

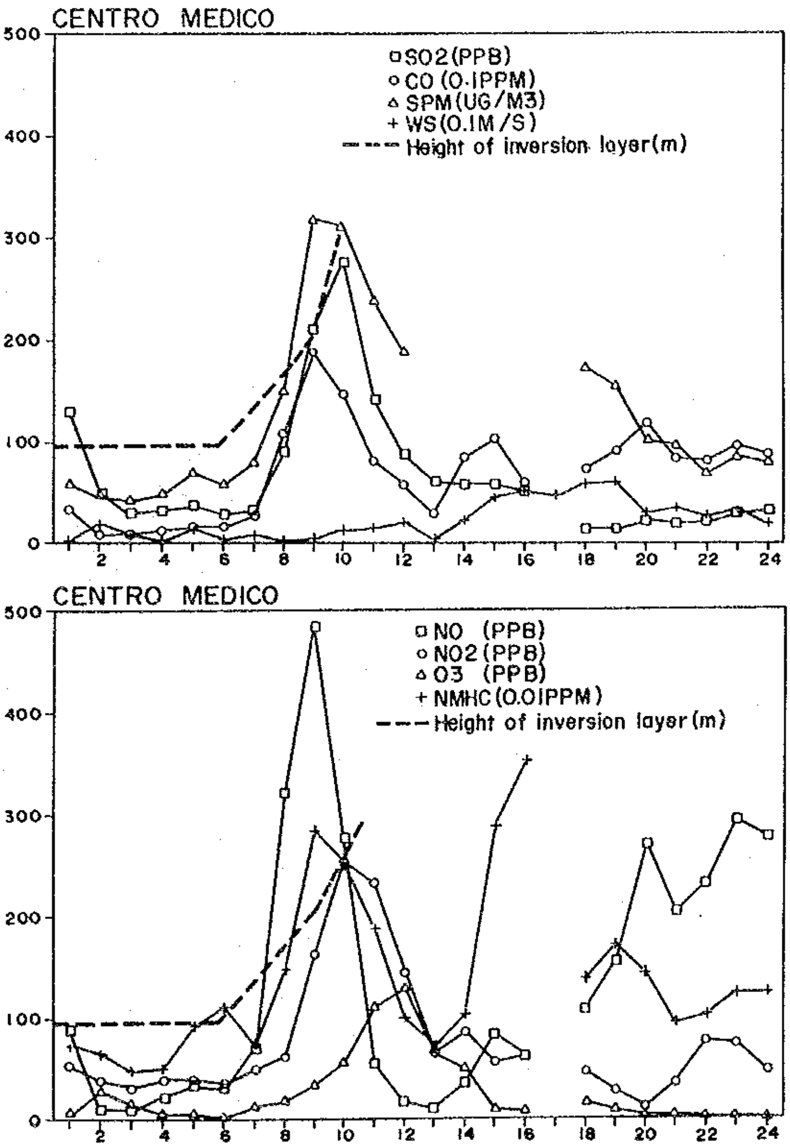


Figure 3 Example of Occurrence of High Pollutant Concentration (February 22, 1988)

3.6 Results of Air Quality Simulation

Performance of the air quality simulation model was evaluated against the actual annual average concentration of SO_2, CO, NOx and NO_2. The model performance was satisfactory for SO_2 and CO, but less satisfactory for NOx and NO_2 because comprehensive model calibration was not possible due to insufficient number of measuring stations.

Areal distribution of SO_2 concentration computed by the model is shown in Figure 6, and that of CO is shown in Figure 7.

Contribution of source categories to the annual average concentration of SO_2 at measuring stations is shown in Figure 4.

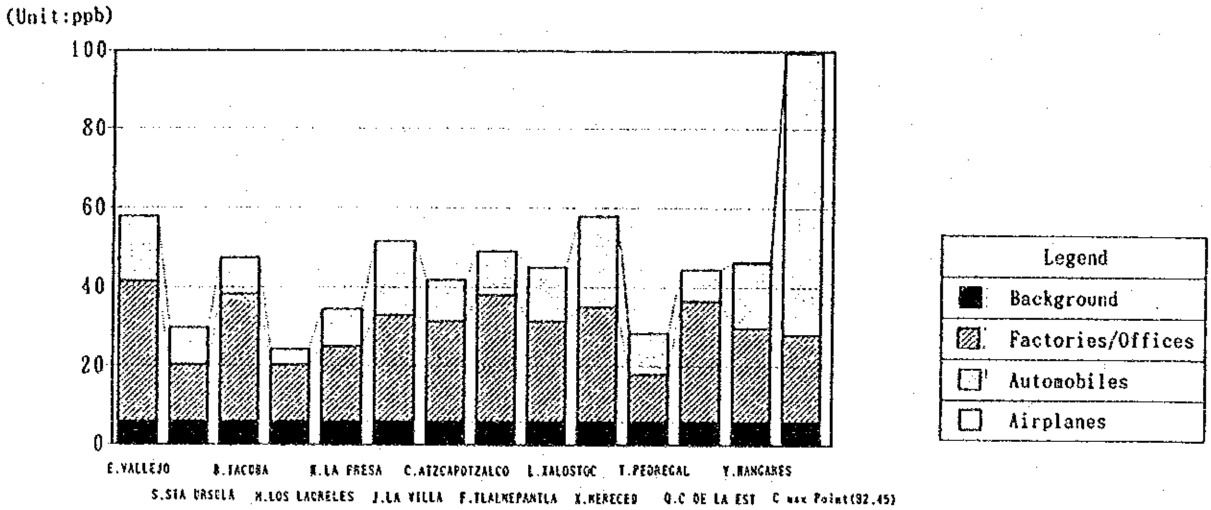


Figure 4 Contribution of Sources to Annual Average Concentration of SO_2 at Measuring Stations

4. Institutional Framework for Air Pollution Control

The Government of Mexico established in 1985 the National Commission for Ecology (CONADE) chaired by the President for the overall coordination of policies to solve growing environmental problems. Against the air pollution problem of Mexico City, a presidential decree called "twenty-one measures against environmental pollution" was promulgated in February 1986 after the detailed discussions made by CONADE. In addition, CONADE announced in 1987 "hundred necessary measures for ecology" which included 36 items concerning air pollution control.

In parallel to the above activities, the law for the protection of environment was reviewed comprehensively and the General Law for Ecological Balance and Environmental Protection was promulgated in March 1988 replacing the old one. Concerning the air pollution of AMCM, responsibilities of federal and local governmental bodies are more clearly defined by this Law including the functions of Ministry of Urban Development and Ecology (SEDUE), department of Federal District (DDF) and the State of Mexico. The SEDUE's functions include establishment of air pollutant emission standards for stationary and mobile sources in cooperation with relevant agencies, prevention and control of air pollution by factories, and establishment of technical measures to reduce air pollutants from motor vehicles. The functions of DDF and the State of Mexico include establishment and operation of the exhaust gas inspection system for motor vehicles used in the respective areas and prevention and control of air pollution by small-scale stationary sources.

The "twenty-one measures" and the "hundred necessary measures" sited above include almost all of practical measures that are considered to be effective to mitigate the air pollution in Mexico City, and some of these measures are already under the process of implementation. Establishment of the emission standards for motor vehicles and factories has been well under way since the promulgation of the Law. From now on, further progress is expected in the abatement of the air pollution paralleled with the progress in establishment of detailed rules for execution of control measures and consolidation of administrative organizations.

5. Source Control Measures and Their Effects

5.1 Stationary Source Control Measures

There are various technologies available for reduction of air pollutant emissions from stationary sources. However, a best available technology is not a best practicable technology under the social and economic constraints. The Government of Mexico has plannd to adopt the practical control measures for stationary sources based on the presidential decree of the "twenty-one measures" and the CONADE's announcement of the "hundred necessary measures," as shown in Table 5.

Table 5 Stationary Air Pollutant Source Control Measures Proposed by the Mexican Government

Pollutant Source	Source Control Measure
Power plants • VALLE DE MEXICO • JORGE LUQUE	a. Fuel switchover from heavy oil to natural gas b. Exhaust gas desulfurization in case when the fuel switchover is not possible c. Cut of operation during winter d. Use of low-NOx burner
Oil refinery • 18 DE MARZO	a. No future expansion of the refinery b. Fuel switchover from heavy oil to natural gas c. Repair of storage tanks to prevent evaporation of HC d. Use of low-NOx burner
Ten major factories • soap and detergent, cement, paper, glass, steel, chemicals, and brewing	a. Fuel switchover from heavy oil to natural gas b. Curtailment of operation in winter c. Use of low-NOx burner
Other factories and small-scale sources	a. Use of low-sulfur heavy oil b. Use of low-sulfur diesel instead of heavy oil

5.2 Control Measures for Automobile Exhaust Gas

The Government of Mexico established the pollutant emission standards for gasoline-powered motor vehicles. Table 6 shows the emission standards for CO and HC at idling operation, and Table 7 shows the emission standards for HC, CO and NOx applicable to new vehicles for 1988 and beyond.

Table 6 Emission Standards for Idling Operation

Model Year	CO (%vol)		HC (ppm)	
	High Altitude	Low Altitude	High Altitude	Low Altitude
-1979	6.0	5.5	700	650
1980-1986	4.0	4.0	500	500
1987-	3.0	3.0	400	400

Table 7 Emission Standards for 1988 and Beyond

Unit: g/km

Item	Model year	88	89	90	91	92	93	94
HC	Passenger car	2.0		1.8	0.7		0.25	
	Commercial vehicle			2.0				0.625
	Light-duty truck			3.0		2.0		0.625
CO	Passenger car	22		18	7.0		2.125	
	Commercial vehicle			22.0				8.75
	Light-duty truck			35		22		8.75
NOx	Passenger car	2.3		2.0	1.4		0.625	
	Commercial vehicle			2.3				1.44
	Light-duty truck			3.5		2.3		1.44

Note: Commercial vehicle: GVW upto 2727 kg
Light-duty truck : GVW 2728 kg - 3000 kg

The authories and industries concerned are preparing to adopt appropriate technologies to meet these standards. To meet the 1993 standards particularly, installation of a three-way catalytic converter is being planned with concurrent introduction of unleaded gasoline which is necessary for the converter to function properly. Introduction of unleaded gasoline is to be carried out by making provision for the following problems.

a. Decrease in octane rating of unleaded gasoline
b. Valve recession
c. Increase of aromatic hydrocarbons in gasoline
d. Increase in cost of gasoline
e. Continuing supply of leaded gasoline to vehicles of older model
f. Prevention of supplying leaded gasoline to the vehicles equipped with a catalytic converter
g. Establishment of an inspection and maintenance system against degradation of catalytic converters

5.3 Effects of the Source Control Measures

Effects of the control measures for stationary sources and automobiles described above were estimated for the year of 1993 and 2001 under the following conditions.

a. Automobile traffic volume, type distribution and road network are assumed to be the same as the present.

b. Old vehicles are replaced by new vehicles at an annual rate of 5%.

c. Progress in implementation of the stationary source control measures by 1993 is tentatively assumed to be about 40%.

Figure 5 shows the change in the quantity of pollutant emissions from the present to the years of 1993 and 2001 corresponding to implementation of the source control measures.

Figure 6 and figure 7 show the change in the areal distribution of annual average concentration of SO_2 amd CO, respectively, computed by the simulation model.

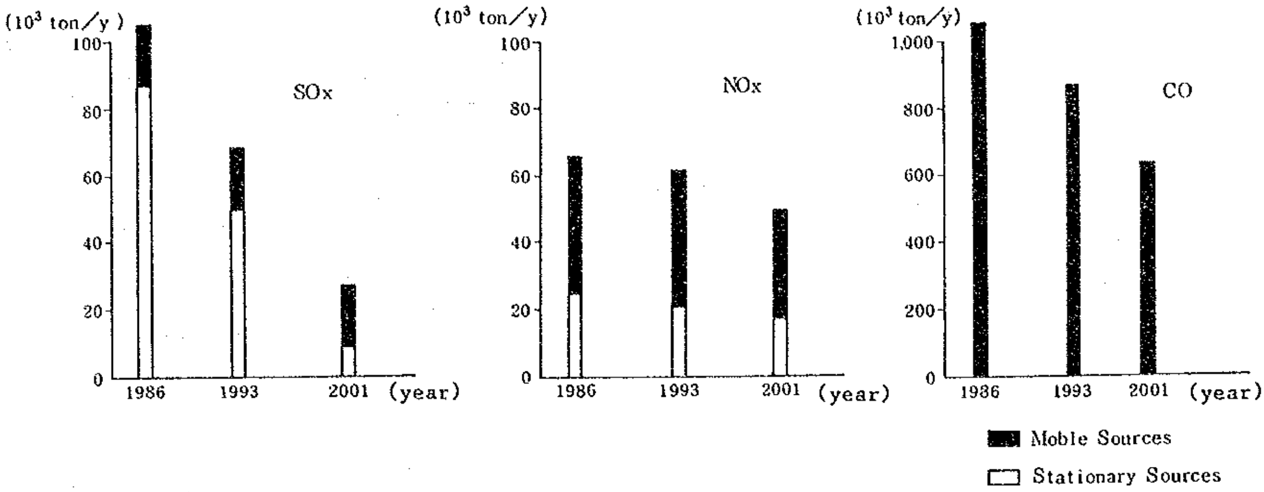


Figure 5 Change in Quantity of Pollutant Emissions Corresponding to Implementation of Source Control Measures

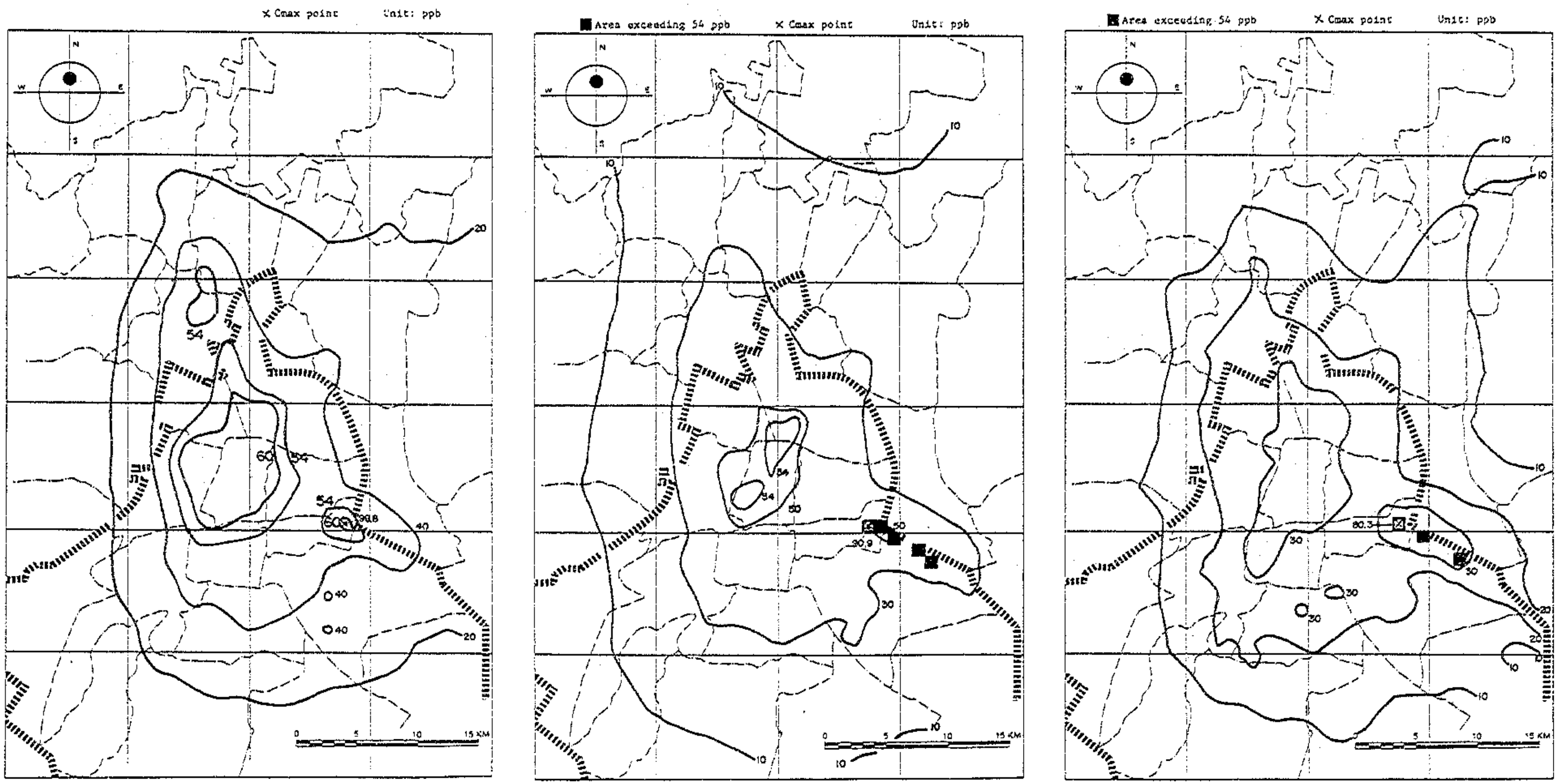
It was statistically estimated that if the daily average concentration of SO_2 at 0.13 ppm prescribed by the ambient air quality standard of Mexico is to be satisfied for 98% of the days of the year, the corresponding annual average concentration would be 54 ppb (0.054 ppm). Similarly, the eight-hour average concentration of CO at 13 ppm prescribed by the standard corresponds to the annual average concentration of 5.0 ppm.

Since the annual average concentration of SO_2 in 2001 is shown to be less than 54 ppb except for a few localities (see Figure 6), the air quality standard can be generally satisfied. This effect is brought by the stationary source control measures with which emissions of SOx decrease to about one-fourth of the present level as shown in Figure 5.

As regards CO, the emissions from motor vehicles in 2001 decrease to about 60% of the present level due to the vehicle emission control, and the ambient air quality standard can be satisfied.

Quantity of NOx emissions in 2001 is about 75% of the present level. A relatively small reduction indicates difficulty of controlling NOx emissions as it is experienced in Japan at present.

The results of the Study presented above indicate that a great degree of improvement can be achieved in the ambient air quality if all of the control measures considered by the Mexican Government are implemented. It should be noted however that besides other assumptions, the estimation for future years does not take account of possible increase in the number of automobiles. It is also pointed out that levels of pollutant concentration are supposed to be higher at roadside zones by the influence of automobile exhaust gas, and deliberate monitoring and countermeasures are required to improve local pollution in these zones.

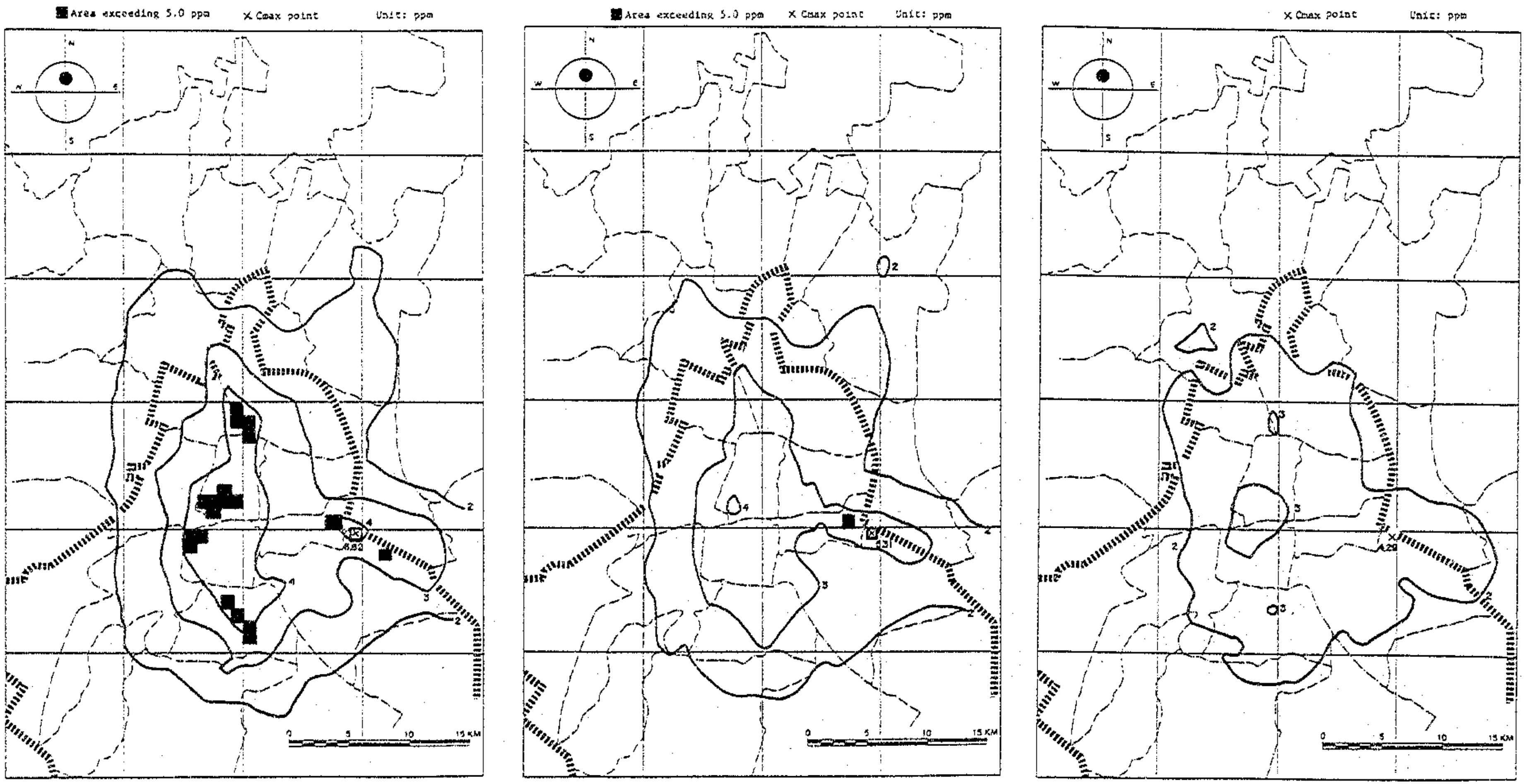


1986

1993

2001

Figure 6 Annual Average Concentration Isopleths for SO_2 (Years 1986, 1993, 2001)



1986 1993 2001

Figure 7 Annual Average Concentration Isopleths for SO_2 (Years 1986, 1993, 2001)

6. Recommendation

(1) Source Control Measures

Implementation of the stationary source control measures being proposed by the Mexican Government will have a large effect in abating the air pollution in Mexico City, particularly of SO_2 pollution. Enforcement of the emission control regulations for motor vehicles set forth by the Government will gradually improve the CO, NOx and HC pollutions, although a relatively long period of time is required to bring about the full effect.

Detailed discussions on the problem of ozone is beyond the scope of this Study. However, a certain degree of improvement associated with the reduction in the NOx and HC emissions may be expected.

It is recommended that the source control measures planned by the Government be implemented as scheduled with rigorous enforcement of the emission regulations for stationary and mobile sources.

As supplements to the Government proposed source control measures, the following measures may be worthy to be considered.

a. installation of a secondary air supply system in vehicles being used

b. Reduction of sulfur content of gasoline

c. Designation of one weekday to each private passenger car to halt the use

(2) Establishment of Detailed Rules and Regulations

General Law for Ecological Balance and Environmental Protection has provided a legal framework for promoting various air pollution control activities. Establishment of detailed rules and regulations relative to the Law is an urgent necessity. Although some vital rules, regulations and standards pertaining to air pollution control have been already set forth by the Government, the task should be continued intensively by the responsible agencies to whom active cooperations should be given by relevant authorities, industries and individuals.

(3) Monitoring and Inspection of Stationary Pollutant Sources

Monitoring of pollutant emissions at large factories can be made effectively by installing automatic measuring devices at sources and establishing a telemetric monitoring system controlled at a central station. Monitoring of a large number of medium to small scale pollutant sources depends largely on manpower. Inspection of smoke emitting facilities should be made in conjunction with giving concrete guidances to improve their performance. Preparation of a pollutant source ledger is also recommended for effective conduct of inspection.

(4) Motor Vehicle Inspection

It is important to maintain performance of emission control devices for life time of motor vehicles that is relatively long in Mexico. Therefore, establishment of a system to carry out periodic inspection of motor vehicles is required. A detailed study of establishing such system is recommended.

(5) Air Quality Monitoring

It is considered necessary to strengthen the existing air quality monitoring network of AMCM in the number of monitoring stations and in the ability of individual stations. It is recommended that a study be carried out to make up a rational monitoring network based on the existing one.

(6) Organizational Consolidation

Mitigation of the air pollution in Mexico City requires responsible agencies such as SEDUE and DDF to undertake a large amount of work in various fields. In the case of DDF, it is considered necessary to increase number of personnel to carry out various works relevant to air pollution control, i.e., management, technological study, vehicle inspection, stationary source inspection, air quality monitoring, legislative works, pubic relation, and etc. It is recommended that such organizational consolidation in conjunction with establishment of personnel training programs be considered.

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CHAPTER 1 INTRODUCTION

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

Mexico City is the capital of the United Mexican States, and is formally called Federal District (DISTRITO FEDERAL: DF). Since the 1950s, urbanization of the city has been making its way mainly toward the north, giving rise to formation of the conurbation which now extends across the border with the State of Mexico. Now, DF and 17 cities (MUNICIPIOS) in the State of Mexico constitute the Mexico City Metropolitan Area (AREA METROPOLITANA DE LA CIUDAD DE MEXICO: AMCM). The population of AMCM has grown to about 18 million, the third place in the world after Tokyo-Yokohama and New York City conurbations, and is expected to increase continually. It is estimated that about 3 million automobiles as well as a number of factories exist within the metropolitan area. A remarkable urban growth has also brought about negative impacts on the environment. The area now suffers from, beside others, serious air pollution due to the following major factors:

1. A large number of mobile and stationary air pollutant sources
2. Incomplete combustion with insufficient amount of oxygen due to the high altitude of the city being over 2200 m.
3. Basined topography that tends to contain air pollutants within the basin particularly when a temperature inversion is formed in the atmosphere.

The Mexican Government has been taking various actions to correct the situation. In addition to the manually operated air quality monitoring network installed in 1960, the government set up a network of 25 automatic monitoring stations with the financial aids of the World Bank, and began its operation in January 1986.

On February 14, 1986, the Government promulgated a presidential decree which declared implementation of a series of concrete air pollution control measures specifying responsible governmental bodies and time limits.

Under these circumstances, the Government of the United Mexican States requested to the Government of Japan, who experienced a considerable degree of success in the field of air pollution control, for conduct a study on the air pollution control plan in the Federal District (hereinafter referred to as "the Study"). In response to the request, Japan International Cooperation Agency (hereinafter referred to as "JICA"), the official agency responsible for the implementation of the technical cooperation programs of the Government of Japan, dispatched in May 1986, a contact mission headed by Prof. Hitoshi Kasuga, Tokai University to Mexico City in order to confirm the details of the request, and to discuss related matters with the officials of the Department of Federal District (hereinafter referred to as "DDF" in Spanish abbreviation). In July 1986, JICA dispatched the second mission, the Preliminary Study Team headed by Mr. Hirotoshi Goto, then assistant to Director General of Air Quality Bureau, Japan Environment Agency, to discuss the scope of work for the Study with DDF. The Scope of Work was agreed upon between JICA and DDF on July 24, 1986. Subsequently, JICA set up a Study Team and an Advisory Committee for the conduct of the Study. The Study began in February 1986 with the first visit of the Study Team and the Advisory Committee to Mexico City.

1.2 Outline of the Study

1.2.1 Objectives of the Study

The Study aims to prepare a guideline for control measures against the air pollution problem in the Mexico City Metropolitan Area based on the findings of on-site investigations in Mexico City and analyses in Japan. Technology transfer from the Japanese side to the Mexican counterpart was also intended in the course of the Study mainly in the fields of measuring ambient air quality, pollutant emission and meteorological factors.

1.2.2 Study Area

The study area, as shown in Figure 1.2.1, covers those areas in the Federal District where air pollution is significant, and the industrial areas in the State of Mexico that stretch northwest and northeast from the Federal District.

1.2.3 Scope of the Study

The scope of the Study is as follows:

(1) Data Collection

1) Meteorology

a. Surface : wind direction and speed, temperature, and humidity

b. Upper level : vertical distribution of wind direction, wind speed and temperature, data related to thermal inversion

2) Ambient Air Quality

a. Sulphur oxides (SOx)

b. Nitrogen oxides (NOx)

c. Carbon monoxide (CO)

d. Ozone (O_3)

e. Hydrocarbons (HC)

3) Mobile Air Pollutant Sources

a. Traffic volume in major roads

b. Number of automobiles in use by automobile type

c. Fuel composition

d. Fuel consumption

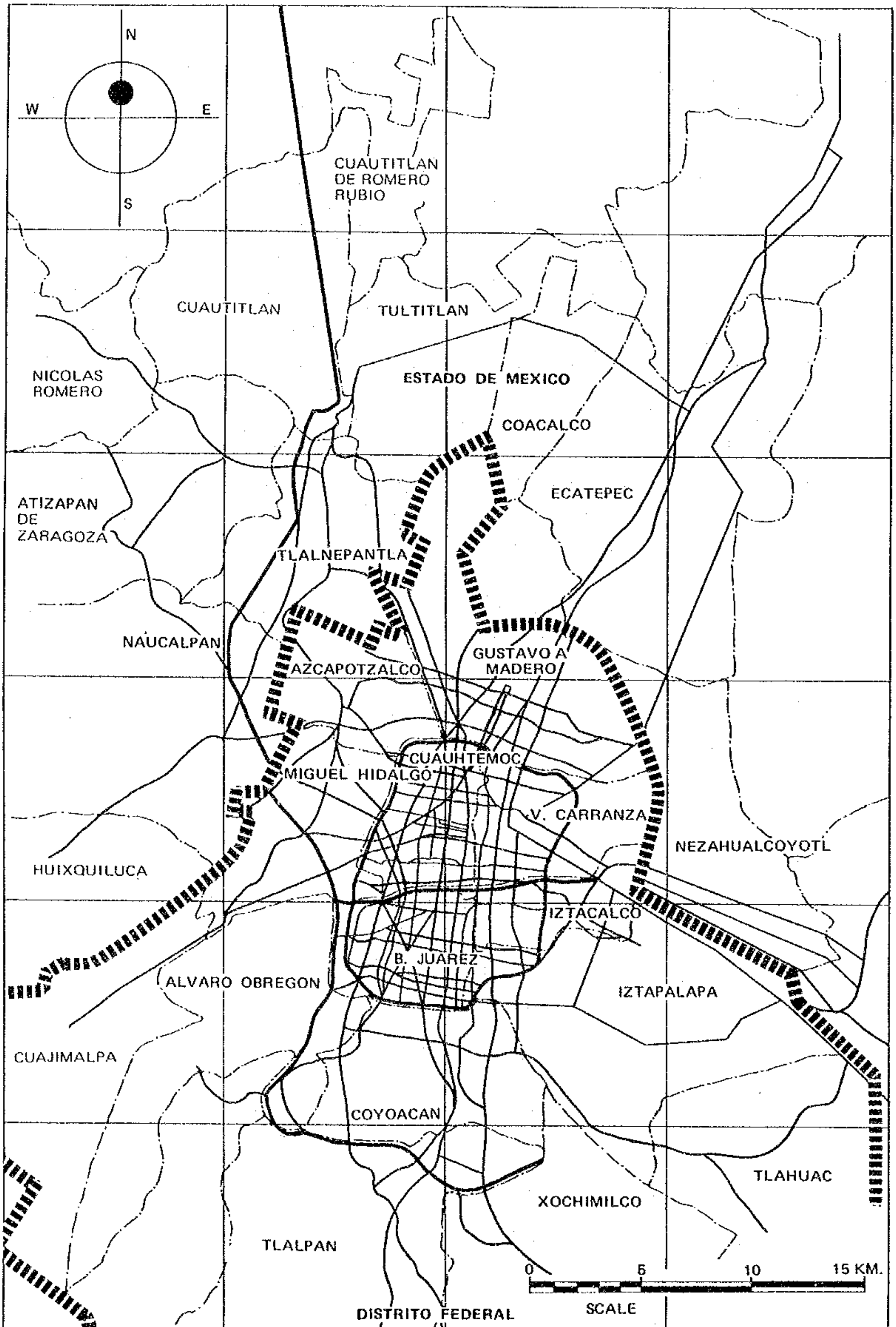


Figure 1.2.1 Study Area

4) Stationary Air Pollutant Sources

a. Factories: number of factories, types of facility, kinds of fuel and their usage, stack height, etc.

b. Emission factors for SOx, NOx and particulates

c. Fuel composition

d. Fuel consumption

5) Social Conditions

a. Present and projected social indicators closely related to air pollution: Population, land-use, etc.

b. Economic development indicators: Demand and supply of energy sources, etc.

c. Present and projected system of transportation: roads, subways, buses, trains and airports, etc.

6) Present and Planned Air Pollution Control Measures

a. Laws, rules and regulations, standards, etc.

b. Source control measures

(2) Investigation of Present State of Air Pollution

1) Meteorological Observation

a. Surface meteorology
observation of wind direction and speed, and horizontal standard deviation of the winds

b. Upper level meteorology
observation of vertical distribution of wind direction, wind speed, and temperature

2) Survey of Mobile Pollutant Sources

a. Traffic volume survey
- road-side count of traffic volume
- count of automobiles using aerophotographs

b. Driving speed test by type of road

c. Emission factor test by type of car using chassis dynamometer

3) Survey of Stationary Pollutant Sources

a. Questionaire on about 500 factories
type of facility, type of fuel and its consumption, quantity of pollutant emission, stack height, etc.

b. Flue gas measurement at 20 factories
   flue gas quantity, concentration of particulate matters, NOx and O_2
c. Analysis of sulphur in heavy oil and diesel at 6 factories

4) Measurement of Ambient Air Quality
   a. Measurement using 2 monitoring cars:
      SO_2, NO, NO_2, NOx, CO, O_3, NMHC, CH_4, THC, and SPM
   b. Measurement of NO and NO_2 by the simplified method
   c. Measurement of NOx at the fixed station
   d. Measurement of TSP, particle size distribution, and content of metallic elements by particle size at 5 stations

5) Survey Related to Chemical Mass Balance Method for Analysis of Sources of Suspended Particulates
   a. Analysis of metallic elements in surface soils

(3) Analysis of the Present State of Air Pollution

1) Analysis of Measured and Existing Data
   a. Air quality and meteorology
   b. Pollutant emission quantity

2) Development of Simulation Model for SOx, NOx and CO
   a. Meteorological model
   b. Source model
   c. Dispersion model

3) Analysis of the Contribution of Pollutant Sources for SOx, NOx and CO
   a. Mobile sources
   b. Stationary sources

4) Analysis of the Contribution of TSP Sources by Chemical Mass Balance Method
   a. Mobile sources
   b. Stationary sources
   c. Soils

(4) Preparation of Guideline for Air Pollution Control Measures

1) Study of Source Control Measures

2) Target of Ambient Air Quality

3) Simulation and Evaluation of Ambient Air Quality Corresponding to Implementation of Source Control Measures

4) Suggestions on the Implementation of Air Pollution Control Measures

1.2.4 Study Work Flow and Time Schedule

The study work flow and the time schedule are shown in Figure 1.2.2 and Figure 1.2.3, respectively.

1.2.5 Technology Transfer

Various measurements in meteorology, ambient air quality and pollutant source were conducted using measuring instruments and equipment brought to Mexico by JICA.

Transfer of measuring technologies to the Mexican counterpart was carried out, at first, explaining methods of setting up the instruments and equipment, operation and maintenance, and data acquisition, then demonstrating and assisting in the actual field works.

The measuring activities to which technical assistances were given were as follows:

(1) Meteorological Observation

a. Measurement of wind direction, wind speed and horizontal standard deviation of wind at ground level using the two-component ultra-sonic anemometer

b. Measurement of vertical profiles of wind direction, wind speed and air temperature using the captive sonde up to 500 m above the ground

c. Measurement of vertical profile of air temperature using low-level sondes up to 1500 m above the ground

d. Measurement of air temperature and humidity at the ground level using the Assmann aspiration psychrometer

e. Measurement of atmospheric pressure at the ground level using the aneroid barometer

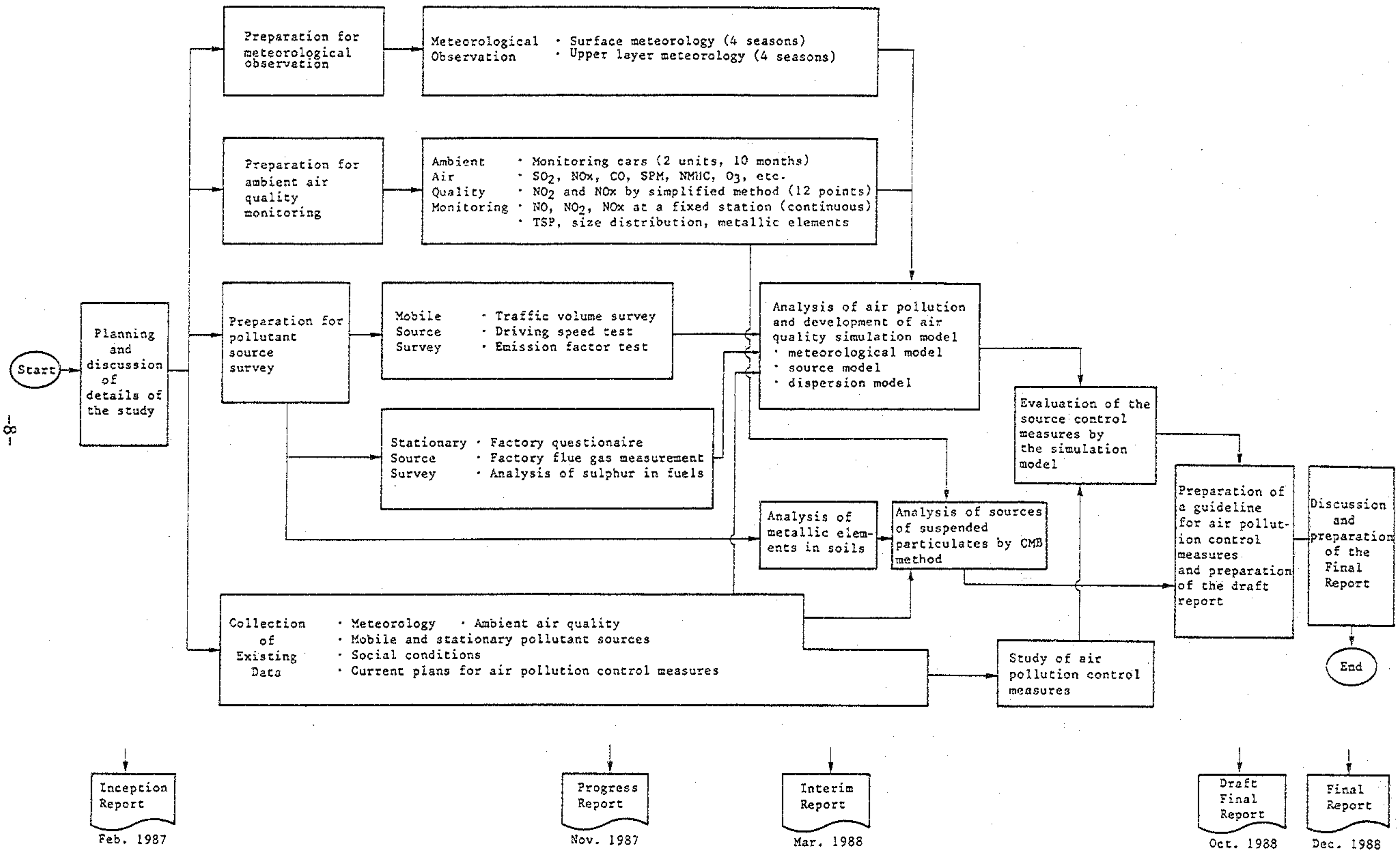


Figure 1.2.2 Study Work Flow

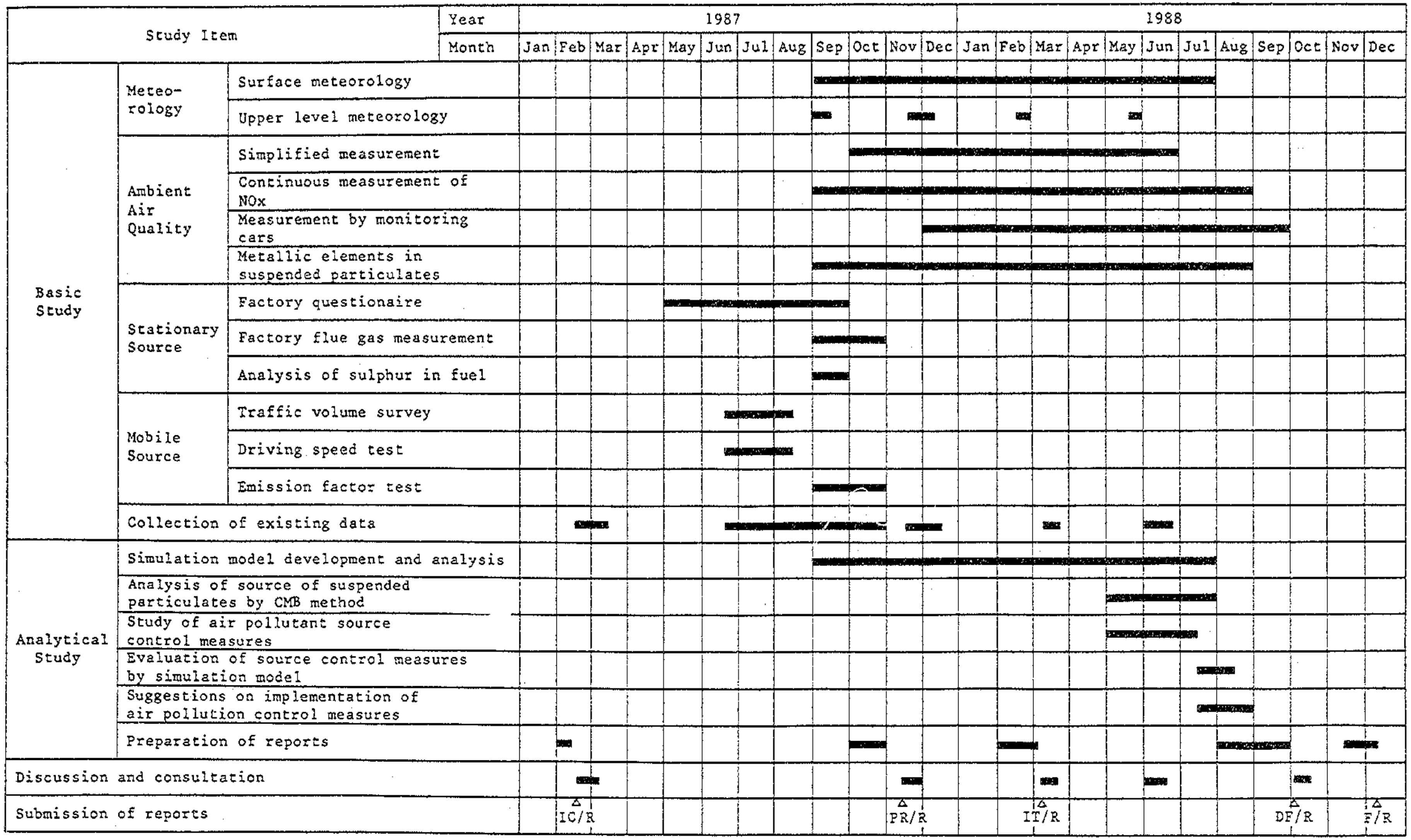


Figure 1.2.3 Time Schedule for the Study

(2) Measurement of Ambient Air Quality

a. Continuous measurement of nitrogen oxides at the fixed station (NO, NO_2 and NO_x)

b. Measurement of ambient air quality using monitoring cars (SO_2, NO, NO_2, NO_x, CO, O_3, NMHC, CH_4, THC, SPM, and wind direction and speed)

c. Measurement of suspended particulates by particle size, and analysis of metallic elements

   1 Sampling by Andersen high volume air sampler

   2 Metallic element analysis by atomic absorption spectrophotometry (Al, K, Ca, Na, Mn, V, Pb, Ni, Zn and Fe)

d. Measurement of nitrogen oxides by the simplified method (NO_2 and NO_x)

(3) Measurement Related to Pollutant Source

a. Measurement of factory flue gas (NO_x, particulates, O_2 and gas flowrate)

b. Analysis of sulphur in factory fuels

1.3 Organization for the Study

1.3.1 Japanese Organization

The Japanese organization for the Study consists of the Advisory Committee and the Study Team of JICA. The members in the Committee and the Study Team are shown in Table 1.3.1 and Table 1.3.2, respectively.

Table 1.3.1 JICA Advisory Committee

Name	Field in Charge	Present Post	Remark
Masayoshi Karasawa	Chairman/ Overall supervision	Assistant to Director General of Air Quality Bureau, Environment Agency	Sept. 6, 1988 -
Hirotoshi Goto	Leader/ Overall supervision	Director of Working Environment Improvement Office, Industrial Safety and Health Department, Ministry of Labor (concurrent assumption with Air Quality Bureau, Environment Agency)	Feb.12,1987 - Sept.5,1988 : Chairman Oct.9 - 21,1988: Leader (JICA Advisory Committee)
Yoshio Yamanaka	Stationary source control	Deputy Director of Air Pollution Control Division, Air Quality Bureau, Environment Agency	Sept. 6, 1988 -
Masaharu Tanaka	Staionary source control	Previous Deputy Director of Air Pollution Control Division, Air Quality Bureau, Environment Agnecy	Sept. 1,1987 - Sept. 5,1988 (JICA Advisory Committee)
Takashi Hayase	Staionary source control	Former Deputy Director of Air Pollution Control Division, Air Quality Bureau, Environment Agency	Feb. 12 - Aug. 31, 1987 (JICA Advisory Committee)
Hidemi Tozawa	Mobile source control	Deputy Director of Automotive Pollution Control Division, Air Quality Bureau, Environment Agency	Feb. 12, 1987 -
Ken Nakamura	Air pollution analysis	Chief Researcher of Atmosphere Dept., Environmental Research Institute, Tokyo Metropolitan Government	Feb. 12, 1987 -
Masataka Sofuku	Air quality monitoring	Chief Researcher of Atmosphere Dept., Environmental Research Institute, Tokyo Metropolitan Government	Feb. 12, 1987 -
Ryuma Hirayama	Planning and management	Staff, Social Development Cooperation Dept., JICA	Feb. 12, 1987 -

Table 1.3.2 JICA Study Team

Name	Field in Charge
Akira Uchida	Team leader/overall supervision
Masayasu Muraoka	Sub-leader/pollutant source analysis
Hidemi Fujimori	Air pollution control planning
Hiroshi Sekine	Stationary source control/factory flue gas measurement
Hiroshi Okano	Meteorological measurement and analysis
Makoto Miyakawa	Automobile exhaust gas analysis and control
Yuhji Shibusawa	Traffic control planning/city planning
Haruo Kikuchi	Air pollution analysis and simulation
Kenichi Yamanaka	Meteorological measurement
Yoichiro Okayama	Air quality monitoring
Ikuo Fujita	Air quality monitoring and laboratory analysis
Ryosuke Fijiwara	Socio-economic analysis
Takashi Kimoto	Calibration of air quality monitoring instruments
Keiji Sodeyama	Calibration of air quality monitoring instruments

Note: Mr. Kanjiro Wakia was the team leader until June 30, 1988.

1.3.2 Mexican Organization

General Directorate of Urban Reordering and Ecological Protection, DDF undertook the Study as the Mexican counterpart. The principal members participated in the Study under Arq. Juan Gil Elizondo, Director General, are shown in Table 1.3.3.

Table 1.3.3 Mexican Study Team

Field in Charge	Name
Supervision	Arq. Francisco de la Vega Aragón
Sub-Supervision	Ing. Victor Gutierrez Avedoy
Stationary pollutant sources	Ing. Julio Huerta
	Ing. Luz Maria Montes
Mobile pollutant sources	Ing. Jose Arviso
	Ing. Ana Cristina Meza Reinoso
	Ing. Hortencia Mergal
	Ing. Victoria Bustos Terrones
Meteorological measurement	Biol. Pablo Gallardo
	Meteol. Pablo Escamilla
Air quality monitoring and laboratory analysis	Ing. Victor Gutierrez Avedoy
	Ing. Juan Manuel Aguilar
Socio-economic analysis	Lic. Silvia Martinez Espinosa

Active cooperations were given by the various governmental agencies including Ministry of Urban Development and Ecology (SEDUE), General Commission for Transportation, DDF, Federal Commission for Electricity, National Meteorological Agency, Civil Aviation Bureau and relevant agencies in the government of the State of Mexico. Many factories also cooperated the Study by supplying necessary data and information.

CHAPTER 2 OVERVIEW OF THE STUDY AREA

CHAPTER 2 OVERVIEW OF THE STUDY AREA

2.1 Geography

Mexico City is situated at lat. 19° 24' N. and long. 99°12' W. in the Mexico Valley at the southern end of the Central Highland. The Central Highland, as shown in Figure 2.1.1, is surrounded by Transversal Volcanic Zone which runs from east to west near lat. 19° N. as well as by The Sierra Madre Occidental (along the Gulf of California) and The Sierra Madre Oriental (along the Gulf of Mexico). The elevation of the Mexico Valley is 2,240 m at the lowest point and is located about 300 km from the Gulf of Mexico and about 400 km from the Pacific Ocean.

The topographical sketches around the Mexico Valley are shown in Figure 2.1.2 and Figure 2.1.3. To the east of the valley, there is the SIERRA NEVADA mountain range including POPOCATEPETL (5425 m above the sea level) and IZTACCIHUATL (5286 m), the second and the third heighest mountains in the United Mexican States.

Figure 2.1.1 Location of Mexico City

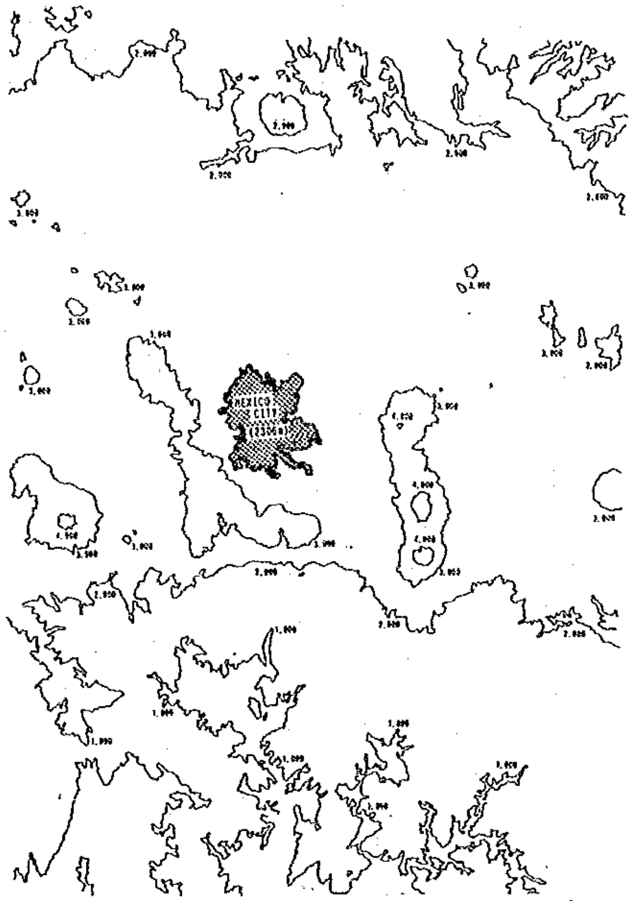


Figure 2.1.2 Topographical Map Around Mexico City

Source: BRAVO, A.H., LA CONTAMINACION DEL AIRE EN MEXICO, UNIVERSO VEINTIUNO, 1987.

Figure 2.1.3 Location of Federal District in the Mexico Valley

From the south to the west of the valley, there are AJUSCO, LAS CRUCES and MONTE ALTO mountain ranges whose altitudes exceed 3000 m. From the north to the northeast, however, there exist only small mountains of the altitudes between 2400 m and 2800m.

In the central part of the valley, there is the Lake of TEXCOCO whose surface area has greatly decreased due to the accumulation of soil deposits originated from the surrounding mountain areas. From the ancient years, the valley had been hydrologically locked out without outflowing rivers, and the TEXCOCO had been subjected to frequent flooding by rains. The flood problem was solved in 1900 when the drainage system for storm-water and sewage water was completed. On the other hand, however, the land subsidence and the drying of the lake began presenting various environmental problems.

Mexico City is called Federal District (DF) in the administrative term, being composed of 16 DELEGACIONES. Due to the rapid increase in the population and the industrial development of the city since the 1940s, the present urban area stretches to the north beyond the border line with the State of Mexico, the area including 17 MUNICIPIOS of the State of Mexico. This conurbation, shown in Figure 2.1.4, is called Mexico City Metropolitan Area (AREA METROPOLITANA DE LA CIUDAD DE MEXICO: AMCM).

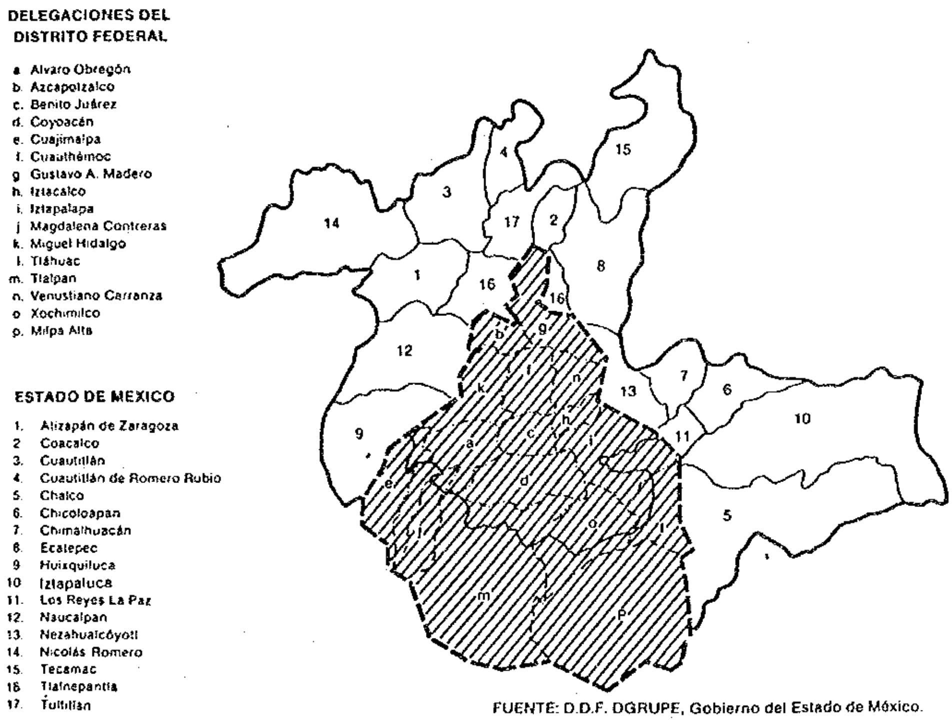


Figure 2.1.4 Administrative Units of AMCM

2.2 Climate

Some climatological factors in Mexico City are shown in Table 2.2.1 and Figure 2.2.1. The temperature remains relatively constant throughout the year with the average of 15°C. The highest monthly mean temperature is 17.4°C in May, and the lowest 12.1°C in January. Annual precipitation totals 725 mm, the most of which is concentrated in the rainy season between June and September. Precipitation is small during the dry season from October to May, particularly in the three-month period from December to February. Humidity averages 61% for the year.

Although the City falls in the geographical category of the subtropical zone it enjoys a warm and dry climate since it is located on the inland plateau of the altitude above 2,200 m.

Table 2.2.1 Climate in Mexico City, 1921-1960

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Monthly average temperature (°C)	12.1	13.8	18.1	17.1	17.4	17.0	15.9	15.9	15.6	14.7	13.3	12.2	15.1
Monthly average humidity (%)	55	49	45	46	55	67	73	73	75	69	64	60	61
Monthly precipitation (mm)	8	5	10	23	55	118	160	145	129	49	17	6	725

Source: Scientific Chronology Yearbook, 1985 (compiled by Tokyo Astronomical Observatory, 1985)

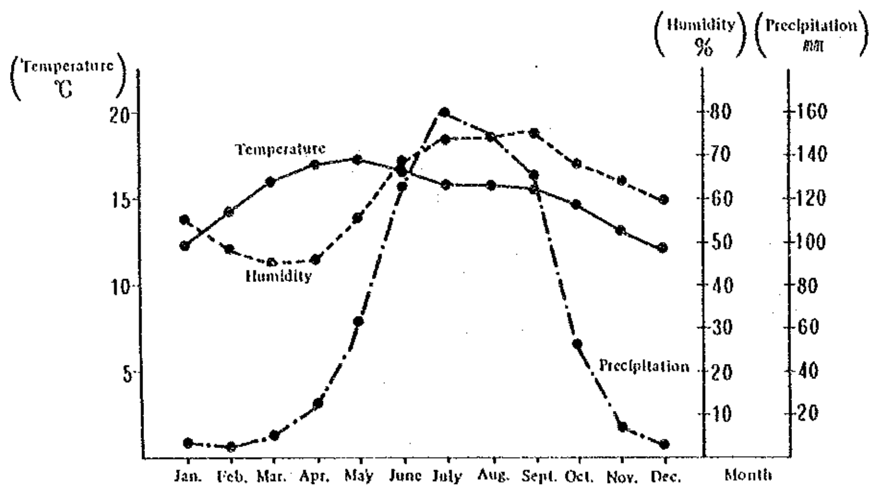


Figure 2.2.1 Climate in Mexico City, 1921-1960

2.3 Population

Table 2.3.1 shows the historical change in population of DF (Mexico City) and the metropolitan part (17 MUNICIPIOS) of the Mexico State, that together constitute AMCM. In 1986, the population reached 10,087,000 in DF and 7,679,000 in 17 MUNICIPIOS in the Mexico of State, totaling 17,766,000. Table 2.3.2 shows the historical changes in the population of the 16 DELEGACIONES in the DF and that of the major MUNICIPIOS in the Mexico State.

Since the 1940s, the annual rate of population growth had been exceeding 5% in AMCM. The rate slightly lowered in the 1970s, but remained on the level of 4% and is still increasing at present.

A population forecast for the year of 2000 gives a total of 27,300,000, of which 12,700,000 is for DF, and 14,600,000 for the Mexico State.

The DELEGACIONES in the DF adjacent to the Mexico State such as G. A. MADERO and AZCAPOTZALCO are the areas where the rate of population growth is remarkablely high. It is the same in some MUNICIPIOS in the Mexico State such as TLALNEPANTLA and NEZAHUALCOYOTL, all close to the DELEGACIONES mentioned above.

Table 2.3.1 Changes in the Population of AMCM

(in thousands of persons)

YEAR	DF	Mexico State	AMCM Total
1950	3,050	-	5,358
1960	4,871	487	5,358
1970	6,871	1,947	8,818
1980	8,831	5,054	13,885
1986	10,087	7,679	17,766

Source: PROGRAMA GENERAL DE DESARROLLO URBANO DEL DISTRITO FEDERAL 1987-1988, DDF-DGRUPE.

Table 2.3.2 Changes in the Population of AMCM by Delegaciones and Municipios

	1930	1940	1950	1960	1970	1980	Remarks
DELEGACIONES in DF	1,230	1,758	3,052	4,871	6,873	8,831	
BENITO JUAREZ			292	442	501	545	Old Mexico City
CUAUHTEMOC			935	980	854	815	
MIGUEL HIDALGO	1,029	1,448	468	661	657	543	
VENUSTIANO CARRANZA			540	749	891	693	
GUSTAVO A. MADERO	(a)	42	205	579	1,186	1,513	
AZCAPOTZALCO	40	63	188	371	535	602	
COYOACAN	24	35	70	170	339	597	
IZTACALCO	9	11	34	199	477	570	
IZTAPALAPA	22	25	77	254	522	1,262	
ALVARO OBREGON	23	32	93	220	457	639	
CUAJIMALPA	5	6	10	19	36	91	
MAGDALENA CONTRERAS	10	13	22	41	75	173	
TLAHUAC	12	14	20	30	62	147	
TLALPAN	15	19	33	61	131	369	
XOCHIMILCO	28	33	47	70	116	217	
MILPA ALTA	13	17	18	24	34	54	
MUNICIPIOS in MEXICO STATE (b)	68	86	134	380	1,781	4,519	
TLALNEPANTLA	10	15	29	105	367	778	
ATIZAPAN DE ZARAGOZA	3	4	5	8	44	202	
COACALCO	1	2	2	4	13	97	
CUAUTITLAN IZCALLI	9	11	14	21	41	36	
CUAUTITLAN DE ROMERO RUBIO	-	-	-	-	-	174	
TULTITLAN	6	7	9	15	52	137	
CHIMALHUACAN	6	7	13	11	20	62	
ECATEPEC	9	11	15	41	216	785	
NEZAHUALCOYOTL	-	-	-	65	580	1,341	
LOS REYES LA PAZ	3	3	4	8	32	99	
HUIXQUILUCAN	11	12	13	16	34	78	
NAUCALPAN	10	14	30	86	382	730	
Total	1,298	1,844	3,186	5,251	8,654	13,350	

Source: Yamazaki, H., Mexico City, Great City in the World Series No. 3, Tokyo Univ. Press, Feb. 1987 (in Japanese)

Note: (a) The population of GUSTAVO A. MADERO in 1930 is included in that of Old Mexico City.
(b) Although 17 MUNICIPIOS are now included in AMCM, five of them were added recently and are not shown in the table.

Since 1950s, the cause of the population increase in DF's four central DELEGACIONES (Old Mexico City), i.e., BENITO JUAREZ, CUAUHTEMOC, MIGUEL HIDALGO and V. CARRANZA, changed from natural increase to social increase, and the population also spread into the surrounding DELEGACIONES. This trend was accelarated in 1960s, extending into the areas of the Mexico States such as NEZAHUALCOYOTL and ECATEPEC. In 1970s, the population of Old Mexico City began decreasing, but the the population of the surrounding area has been continually increasing.

2.4 Industry

Table 2.4.1 shows the distribution of workers in DF classified by industrial sector. From 1970 to 1980, the sectorial distribution in DF changed markedly. In 1980, "service, public service,and others" had the largest working population (49.2%), followed by manufacturing (12.4%), mining (10.1%), and construction (9.8%). The decrease of manufacturing population in DF since 1970 is remarkable. It may be a reflection of the fact that development of manufacturing industry in AMCM in recent years has been realized mostly in the areas of the Mexico State. According to the questionaire survey, chemical, steel, metals, food, ceramics, and paper are major types of manufacturing industory in AMCM.

Table 2.4.1 Sectorial Distribution of Workers in DF

Industrial Sector	1960		1970		1980	
	(Persons)	(%)	(persons)	(%)	(persons)	(%)
Agriculture, silviculture, stock-forming, fishery	46,516	2.7	49,164	2.2	202,336	6.1
Mining, petroleum	11,829	0.7	18,435	0.8	333,858	10.1
Manufacturing	532,202	30.4	665,486	29.8	407,001	12.4
Construction	118,172	6.7	122,248	5.5	321,627	9.8
Electricity, gas, water	14,943	0.9	13.611	0.6	72.810	2.2
Commerce, finance	305,990	17.5	310.540	13.9	297,828	9.0
Transportation	102,228	5.8	96,094	4.3	37,105	1.1
Service, public service, and others	620,074	35.4	955,408	42.8	1,621,050	49.2
Total	1,751,954	100	2,230,986	100	3,293,615	100

Source: ANUARIO ESTADISTICO DEL DISTRITO FEDERAL, 1984, TOMO I, INSTITUTO NACIONAL DE ESTADISTICA, GEOGRAFIA E INFORMATICA, FEB. 1985.

2.5 Land Use

The City (DF) has a total land area of 1,503 km^2. Table 2.5.1 and Figure 2.5.1 show the break-down of land utilization. The northern part is the urbanized area which accounts for about 36% of the total area. Neighbouring zones in the Mexico State to the north of DF are under the process of rapid urbanization and population growth in the recent years. Many factories and lands for industrial use are concentrated in the areas across the northern limit of DF.

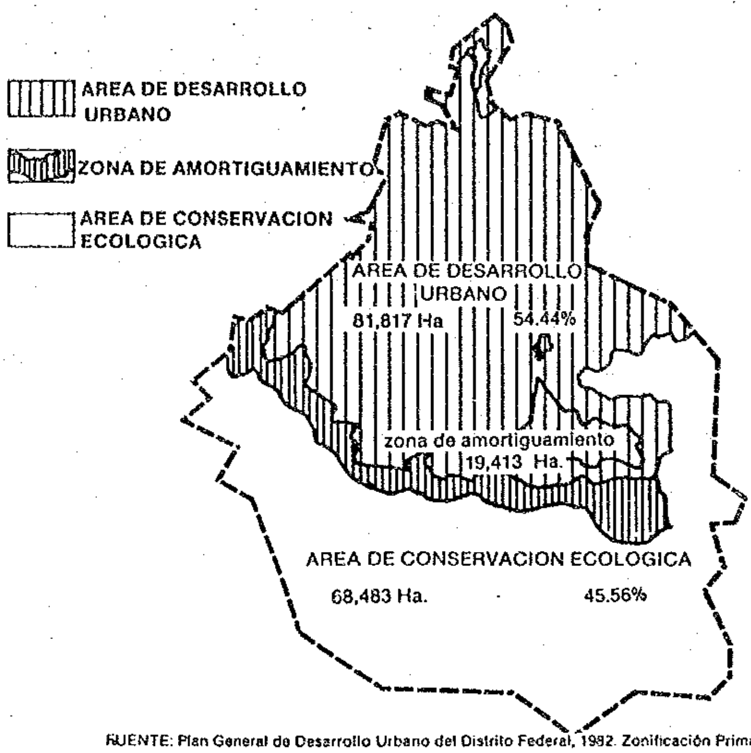
Table 2.5.1 Present Land Use in DF

Primary Category	Major land uses	Area (km^2)	Distribution ratio (%)	Ratio (%) of the primary category
Urbanized area	Residence	224	41.3	
	Service	60	11.1	
	Industry	25	4.6	
	Mixed	41	7.6	
	Open space	66	12.2	
	Road	126	23.2	
	Subtotal	542	100.0	36.1
Reserved area		82		5.5
Buffer zone	Forest	88	45.4	
	Forest/residence	29	14.9	
	Farm	66	34.0	
	Farm/residence	7	3.6	
	National park	1	0.5	
	Urban area	3	1.5	
	Subtotal	194	100.0	12.9
Conservation area	Farm	136	19.9	
	Forest	541	79.1	
	Urban area	7	1.0	
	Subtotal	684	100.0	45.5
Total		1,503		100.0

Source: DDF, PLAN DE DESARROLLO URBANO, 1982, CUADRO A.

Note: The terms "forest/residence" and "farm/residence" refer to the areas of woodland and farmland dotted with houses. The "urban areas" in both buffer zone and conservation area are those not connected to other streets in farm villages.

ZONIFICACION PRIMARIA 1982



FUENTE: Plan General de Desarrollo Urbano del Distrito Federal, 1982. Zonificación Primaria 1982.

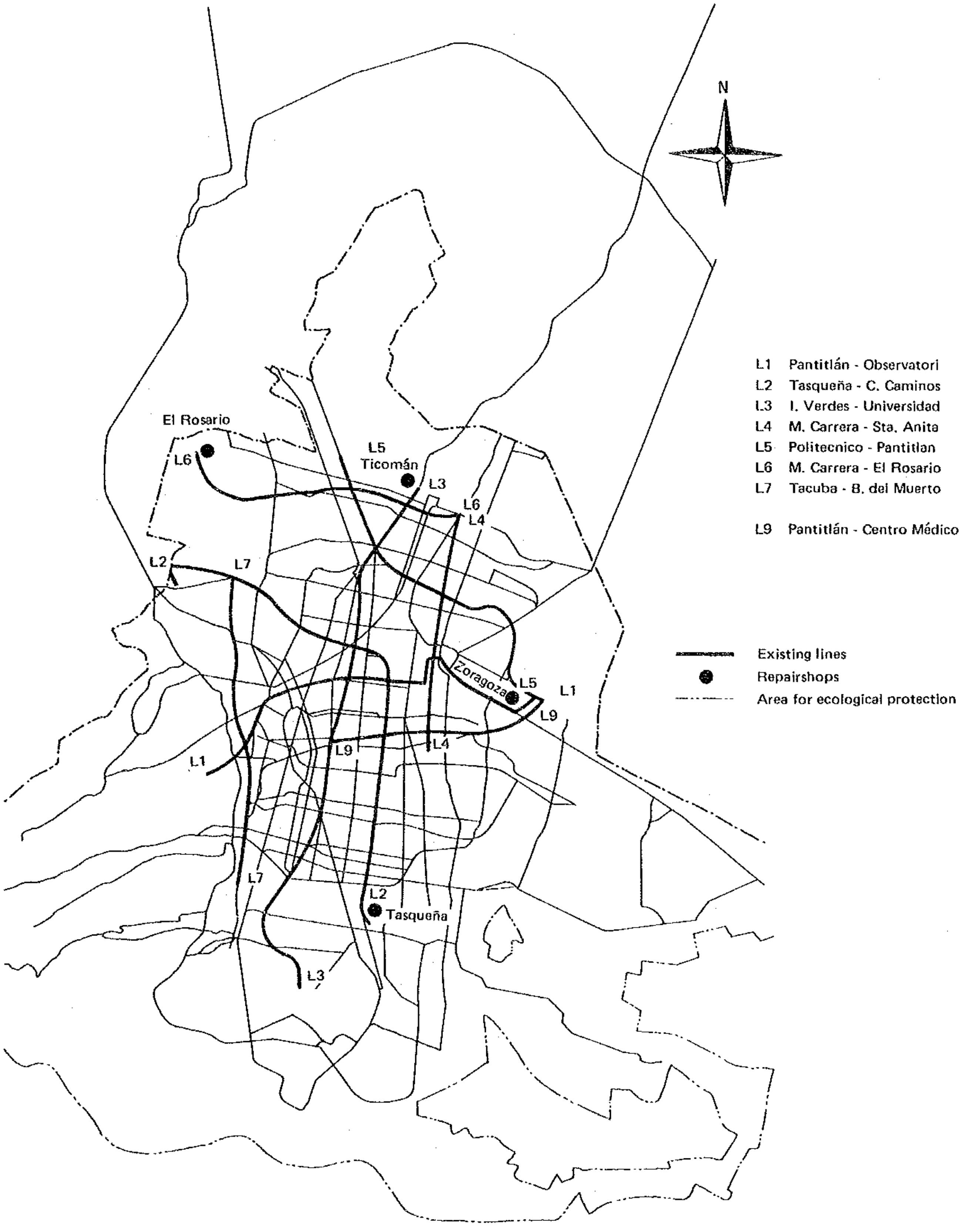
Figure 2.5.1 Present Land Use in the DF

2.6 Transportation

Major traffic infrastructures in the City include the primary road network shown in Figure 1.2.1 and Figure 3.4.1 and the subway network shown in Figure 2.6.1, the trolley and light train network shown in Figure 2.6.2, railroads, and an airport. About 80% of the total passengers in the City is dependent on automobiles, such as private cars, buses, and taxis.

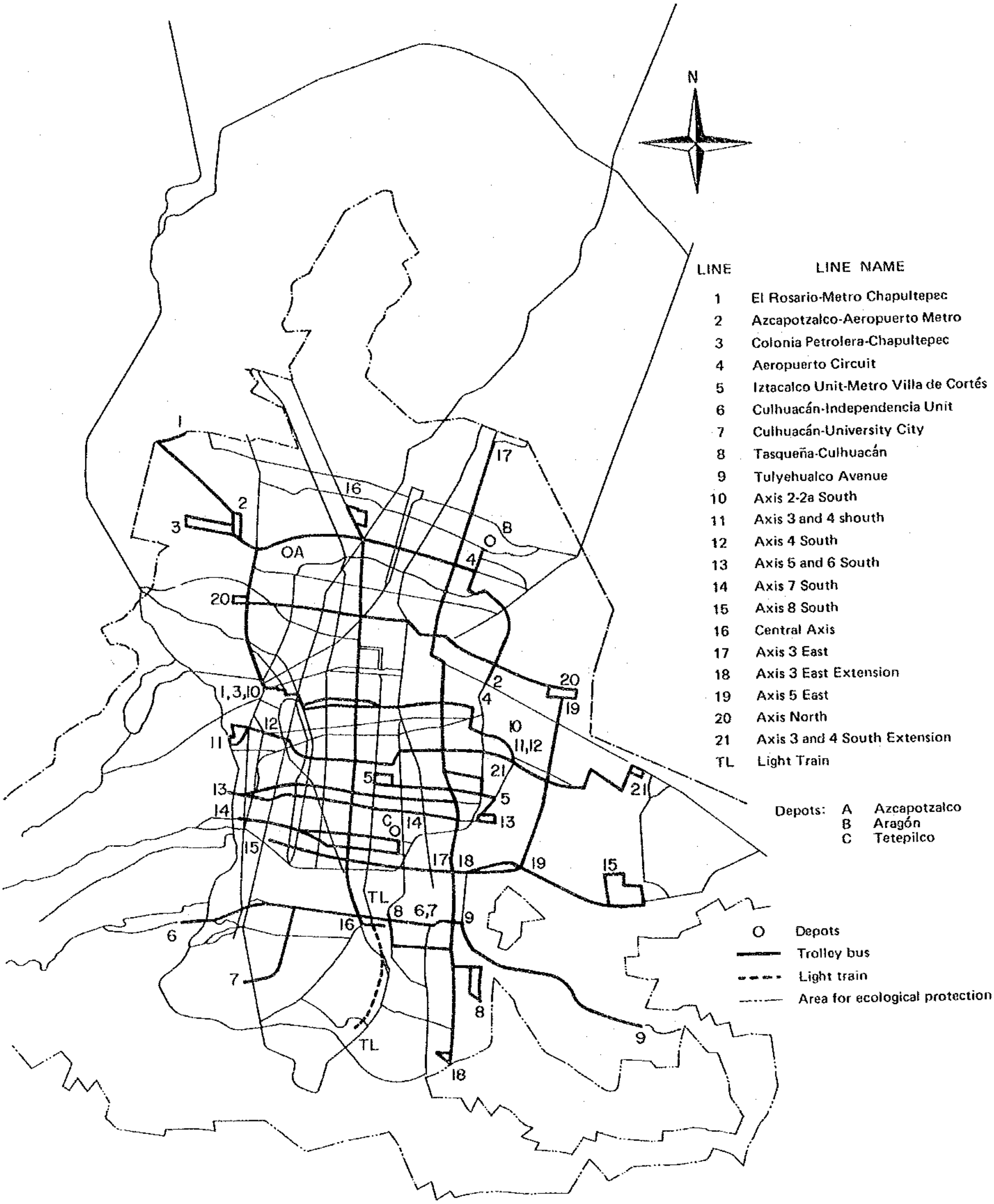
Table 2.6.1 shows the numbers of various passenger transport vehicles in AMCM in 1985, and Table 2.6.2 shows the modal distribution of passengers in AMCM in 1983, 1985 and 1987.

Construction of subways has been well under way since 1968 when the Mexico Olympic Games were held. Eight subway lines are under operation at present. But the network is limitted within the area of DF and extention to the urbanized areas of the Mexico State is not expected in the foreseeable future.



Source: DDF-CGT

Figure 2.6.1 Subway Network in Mexico City



Source: DDF-CGT

Figure 2.6.2 Trolley Bus and Light Train Network in Mexico City

Table 2.6.1 Numbers of Passenger Transport Vehicles in AMCM

Transport Means		Number	Ratio (%)
Public Transport	Subway	2,075	
	Urban bus	4,931	
	Suburban bus	6,719	
	Taxies	147,631	
	Trolley bus	310	
	Sub-total	161,666	5.0
Truck and motorcycle		435,000	15.0
Private car		2,350,000	80.0
Total		2,946,666	100.0

Source: PROGRAMA GENERAL DE DESARRROLLO URBANO DEL DISTRITO FEDERAL 1987 - 1988, DDF-DGRUPE.

The urban buses, that had been privately operated, were made under the unified management of DDF in 1981 as "RUTA 100". The four terminal bus stations were constructed in the off-central areas of the City, and the entries of suburban buses into the central area are being controlled.

As to the rail roads, there are five lines of Mexico National Railways connecting DF to other local cities, and the number of passengers is slowly increasing in the recent years. Reorganization of the rail road system connecting DF and other state capitals is underway, and so far the construction of a double track between Mexico City and QUERETARO is completed.

Table 2.6.2 Modal Distribution of Passenger Transport

	1983(1)		1985(2)		1987(3)	
	Passengers (million/day)	Ratio (%)	Passengers (million/day)	Ratio (%)	Passengers (million/day)	Ratio (%)
Subway	6.514	29.06	4.114	19.98	4.43	17.75
Urban bus	5.817	25.97	6.100	29.62	6.70	26.84
Suburban bus	3.145	14.04	2.445	11.87	3.73	14.94
Trolley bus & light train	0.820[a)]	3.66	0.601	2.92	0.78	3.13
Taxies	1.889	8.21	3.110	15.10	4.90	19.63
Private car	4.265	19.09	3.980	19.33	4.42[a)]	17.71
Others[b)]	--	--	0.245	1.19	--	--
Total	22.450	100	20.595	100	24.96	100

Source: (1) PROGRAMA GENERAL DE DESARROLLO URBANO DEL DISTRITO FEDERAL 1987-1988, DDF-DGRUPE.

(2) ANUARIO DE TRANSPORTE Y VIALIDAD 1985, DDF-CGT.

(3) PROGRAMA INTEGRAL DE TRANSPORTE Y VIALIDAD 1988-2000, DDF-CGT

Note: a) The figure includes passengers of "Others".

b) "Others" include school bus, bicycle, motor cycle and truck.

2.7 Energy

Supply of electricity to DF and the neighboring areas is under the responsibility of Federal Commission for Electricity (LA COMISION FEDERAL DE ELECTRICIDAD: CFE). Two central thermoelectric plants are located in the Mexico Valley. One is VALLE DE MEXICO central plant with a capacity of 766MW, and the other is ING. JORGE LUQUE central plant with a capacity of 224MW. These two plants together supply 25% of the total demand in DF. The rest is supplied by the hydroelectric plants located outside the Mexico Valley. At VALLE DE MEXICO plant, fuel was partially changed from heavy oil to natural gas after the presidential decree of "Twenty-one measures for the control of the air pollution", thereby contributing to alleviate the air pollution.

Production, refinement and supply of petrolic fuels in the United Mexican States are undertaken collectively by the Mexican Petroleum Corporation (PEMEX). Domestically produced crude oil is refined at nine refineries in the country and supplied nationally through the supply network. There is one refinery in the DF at AZCAPOTZALCO, which serves as the supply base of the petrolic fuels to the DF and neighboring areas. This refinery improved the octane rating of gasoline in 1986 by enhancing the process of naphtha reforming.

CHAPTER 3 PRESENT STATE OF AIR POLLUTION IN MEXICO CITY

CHAPTER 3 PRESENT STATE OF AIR POLLUTION IN MEXICO CITY

Rational planning and implementation of air pollution control measures must be based on well-founded understanding on essential components associated with the air pollution problem. These components are, as shown below, the causes and the influential factors of the problem and the results, i.e., the existing state of air quality.

(Causes)

Quantity of air pollutants discharged into the environment
- types of pollutant
- spatial distribution
- temporal distribution
- method of discharge

(Influential Factors)

Meteorological condition (winds, temperature, etc.)
- spatial variation
- temporal variation

Geography

Topography

↓

(Results)

Ambient air quality (pollutant Concentration)
- types of pollutant
- spatial distribution
- temporal variation

This Chapter presents the results of the investigations conducted on these components and the results of the analysis made in atempt to understand quantitative relationship between these components.

3.1 Meteorological Observation

This section describes the results of the analyses made on surface and upper meteorological conditions for the purpose of understanding the regional characteristics of the meteorology around Mexico City, in particular, the features of daily wind variation and structure of thermal inversion unique to the basined topography. Meteorological data used for analyses include the results of the on-site observation and existing data obtained as shown in Table 3.1.1. Figure 3.1.1 shows location of meteorological observation point where these data were obtained.

Table 3.1.1 List of Data for Meteorological Analysis

Category	Item	Meteorological Factor	Point	Period
On-site Observation	Surface meteorology	Wind direction and speed	CENTRO No.5	Sept. 8, 1987 - May 27, 1988
		Turbulence of wind		Summer: Sept. 8 - Sept. 19, 1987 Autumn: Nov. 19 - Dec. 3, 1987 Winter: Feb. 17 - Feb. 24, 1988 Spring: May 20 - May 27, 1988
	Upper Level meteorology	Wind direction and speed, and air temperature		
Existing Data Collected	Surface meteorology	Wind direction and speed	TACUBAYA	Jan. 1 - Dec. 31, 1986
	Upper Level meteorology	Wind direction and speed, and air temperature	AEROPUERTO	Jan. 1 - Dec. 31, 1986

3.1.1 Items and Methods

(1) Surface Meteorology

The on-site observation of surface meteorology included measurement of wind direction, speed, and turbulence (standard deviations of wind direction and speed) at the CENTRO NO. 5 point. The methods of the observation are shown in Table 3.1.2. Turbulence was measured at the same times with the on-site upper level observation.
The existing data of wind direction and speed at the TACUBAYA station for the period from January 1 to December 31, 1986 were collected.

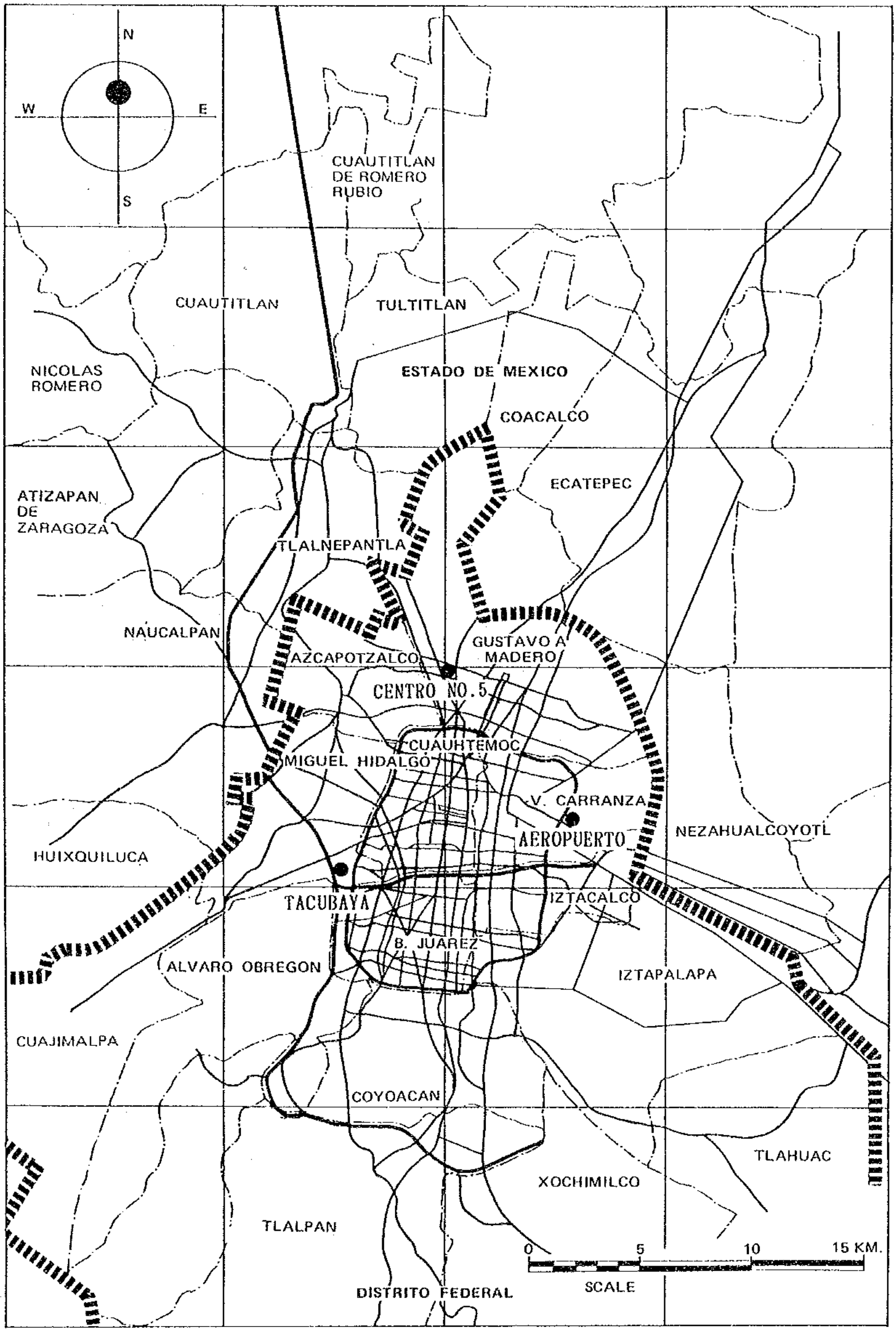


Figure 3.1.1 Meteorological Observation Points

Table 3.1.2 Methods of the On-site Surface Meteorological Observation

Item	Equipment	Height	Reading Method
Wind Direction and Speed	SA-200 type two-component ultrasonic anemometer	15m above the ground	Hourly continuous
Turbulence			

Note: Turbulence is measured in terms of standard deviations of horizontal wind direction and speed

(2) Upper Level Meteorology

The on-site observation of upper level meteorology included measurement of wind direction and speed and air temperature at the CENTRO No. 5 point. The methods of the observation are shown in Table 3.1.3.

The existing data collected are the upper wind and air temperature measured for the period from January 1 to December 31, 1986 at the AEROPUERTO point.

Table 3.1.3 Methods of the On-site Upper Meteorological Observation

Items	Equipment	Time	Altitude	Remarks
Wind direction and speed, air temperature	Captive sonde	Eight times a day at 3:00, 6:00 9:00, 12:00, 15:00, 18:00, 21:00, and 24:00	Up to 500 m above the ground, in 50 m steps	Additional observation made at 7:30 and 10:30 for two to three days when remarkable ground level inversion occurred.
Air temperature	Low-level sonde	Once a day at 13:30, and during stormy weather	Up to 1,500 m above the ground, in 50 m steps	

3.1.2 Results of the Observation

(1) Surface Meteorology

1) Wind Direction Appearance Trend

Figure 3.1.2 shows the appearance frequency of wind directions and wind speed in the three seasons and the entire period from September 1987 to May 1988 at the CENTRO No. 5 point.
Large variation of the wind direction between daytime and nighttime and relatively low wind speed indicate the considerable degree of influence of the local topography, i.e., mountain-valley winds.
The appearance frequency in the total period shows that the governing wind directions in the daytime are ESE to ENE and NW to NNW, and those in the nighttime WSW to NW. The frequent wind speed for the northwestern winds was below 3.9 m/s both in daytime and nighttime and that for the eastern winds in the nighttime range from 0.5 m/s to 1.9 m/s. Wind speed exceeding 4.0 m/s occurred about 9% of the total period, but that above 8.0 m/s was not observed.
There is a certain degree of seasonal variation in the wind direction.
The wind direction with high appearance frequency in each season is as follows: E, SW, and SWS in the daytime and SW to NW in the nighttime for spring (March to May), NW both in daytime and nighttime for autumn (September to November), and E in the daytime and NW in the nighttime for winter (December to February).

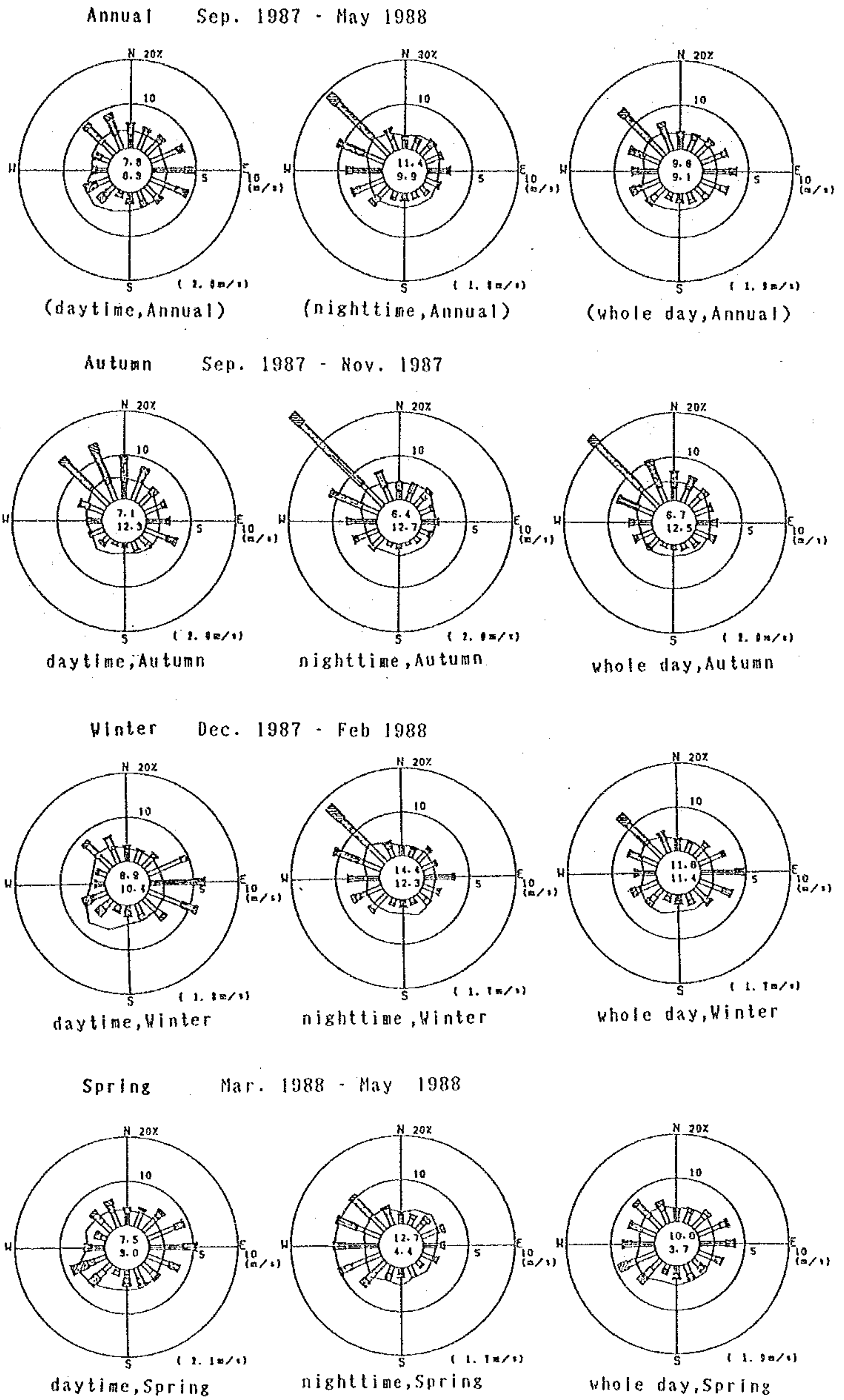
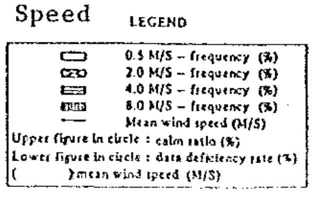


Figure 3.1.2 Appearance Frequency of Wind Directions and Wind Speed
Location: CENTRO No. 5
Period: September, 1987 to May, 1988



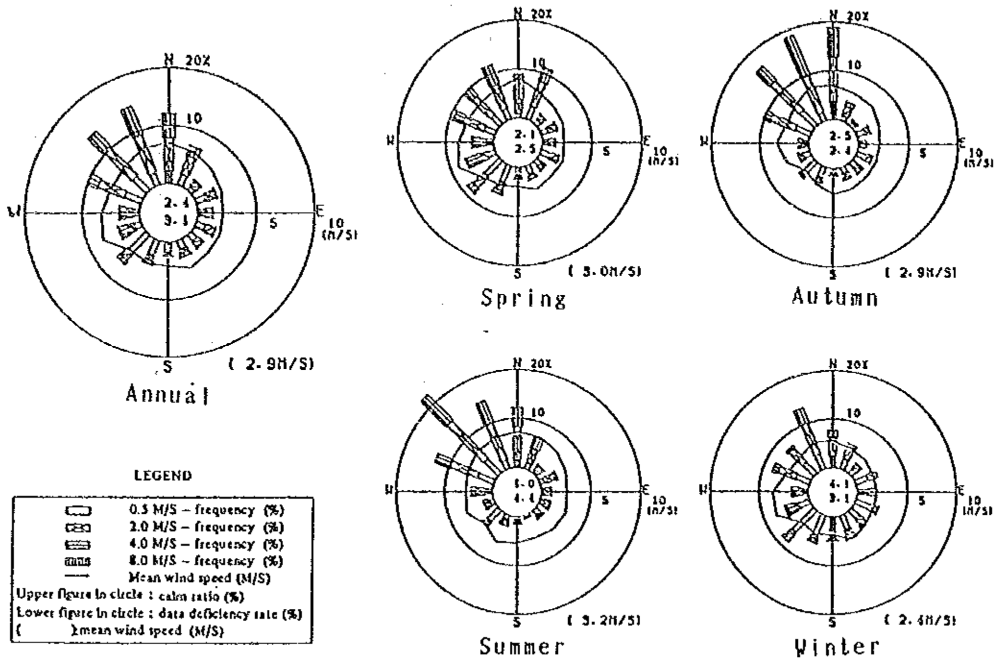


Figure 3.1.3 Appearance Frequency of Wind Directions and Wind Speed
Location: Tacubaya
Period: January to December, 1986

Figure 3.1.3 shows the appearance frequency of wind directions and wind speed at the TACUBAYA station for the period from January to December 1986. The frequent wind direction is NW, the trend as that for the CENTRO No. 5 point. However, the wind direction appearance trend is different, with the eastern wind direction appearing less at the TACUBAYA station.

2) Monthly Variation of Wind Speed

Monthly variation of the wind speed at CENTRO No. 5 and TACUBAYA is shown in Figure 3.1.4. Despite the difference in the statistical years, two stations show a general trend of high speed in summer or autumn and low speed in winter.
The wind speed at the CENTRO No. 5 point was highest at 2.1 - 2.3 m/s in September and October and low at 1.6 - 1.7 m/s in November to January. The wind speed at TACUBAYA was highest at 3.4 - 3.5 m/s in August and September and lowest at 2.1 -2.3 m/s in December to January.

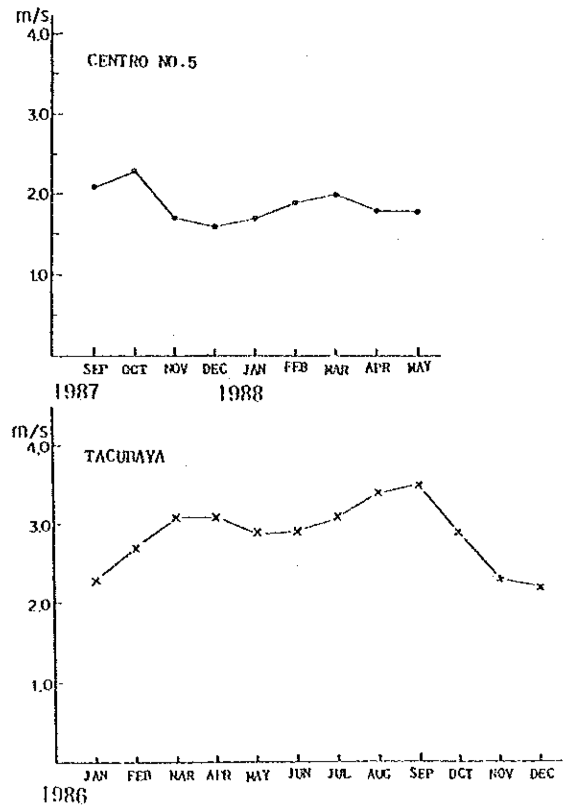


Figure 3.1.4 Monthly Change in Wind Speed

3) Standard Deviation of Wind Direction

Appearance frequency of standard deviation of direction of surface wind for daytime and nighttime measured during the same period with the upper level observation is shown in Figure 3.1.5

Standard deviation below 10 degree did not appear either in daytime or nighttime. The standard deviation classes with high appearance frequency were four (20 - 60 deg) at 10 -20% in the daytime and two (10 - 30 deg) at 14 - 55% in the nighttime. Overall, the standard deviation values are rather high. This may be due to relatively low speed of winds and the location of the measuring point (in the urban area dotted by relatively high buildings).

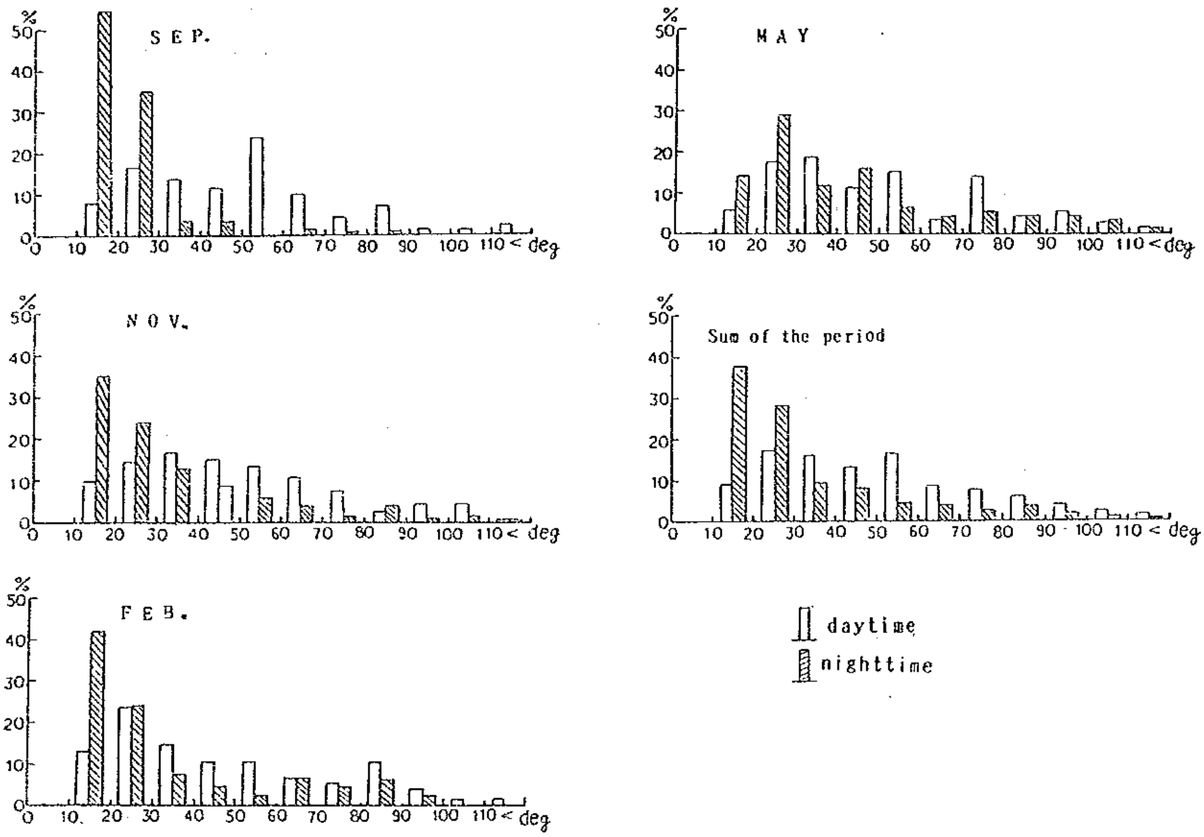


Figure 3.1.5 Appearance Trend of Standard Deviation of Wind Direction
Location: CENTRO No. 5
Period: Sept., 1987 - May, 1988

4) Hourly Change of the Most Frequent Wind Direction

Figure 3.1.6 shows the most frequent wind direction at each hour in each month at CENTRO No. 5 and TACUBAYA.
The wind direction at CENTRO No. 5 in the daytime changed from month to month, but in the nighttime, west to north winds were prevailing in all months.
At TACUBAYA, the wind direction in the nighttime was northwest as in the case of CENTRO No. 5 but the north wind prevailing in the daytime.

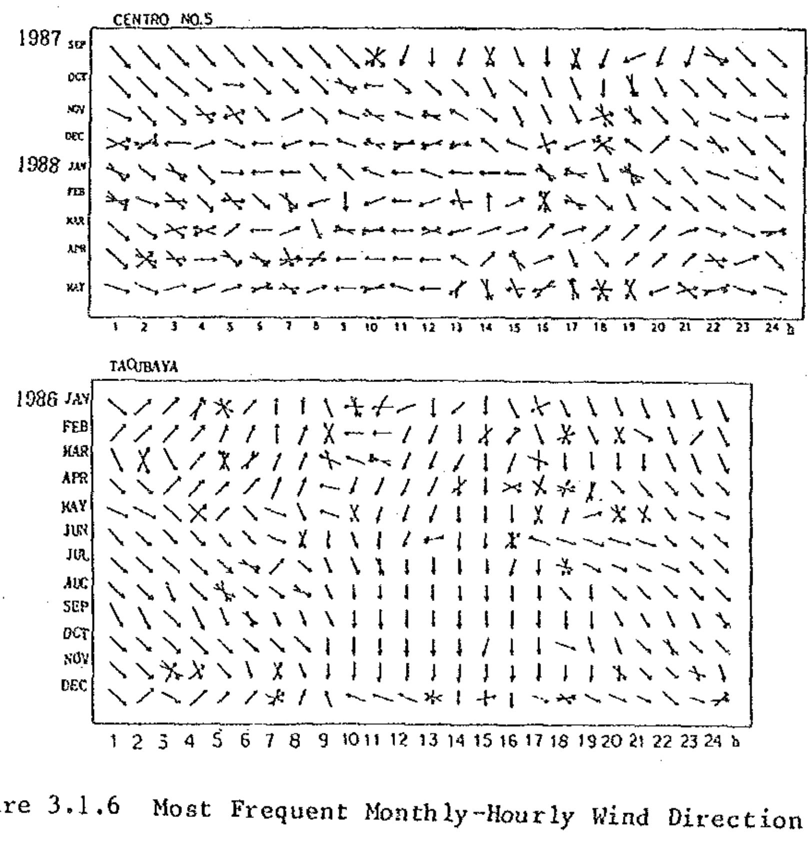


Figure 3.1.6 Most Frequent Monthly-Hourly Wind Direction

5) Hourly Change of the Wind Speed

Figure 3.1.7 shows diagrams of the speed of the wind with the most frequent monthly-hourly direction at CENTRO No. 5 and TACUBAYA.

The wind speed was lowest at around 8:00 and highest at around 18:00: The low speed in the morning is considered due to the stable atmospheric stratification caused by the radiation cooling. The high speed in the evening may be attributed to the rise of air temperature near the surface through solar radiation, creating convective air currents.

CENTRO NO. 5 Unit: 0.1 m/s

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24 h
1987	SEP	22	22	17	18	17	17	15	17	17	14	15	13	17	17	23	26	29	35	32	26	23	23	26	25
	OCT	21	19	16	14	12	13	14	11	13	14	15	21	22	25	27	35	37	36	31	25	30	32	30	27
	NOV	14	12	11	10	11	9	8	8	8	12	13	14	16	22	22	27	32	31	27	20	20	18	17	17
	DEC	12	11	9	10	7	7	8	9	9	11	12	15	18	18	19	23	25	27	26	23	19	21	20	17
1988	JAN	18	13	13	9	9	10	9	8	11	12	15	14	19	19	19	23	26	27	26	24	26	24	19	19
	FEB	16	13	12	11	10	8	10	7	9	12	14	15	17	19	26	25	31	38	35	27	23	25	24	21
	MAR	14	14	11	11	11	11	10	8	10	14	21	22	21	29	27	33	38	37	34	28	21	19	22	16
	APR	15	11	11	9	8	7	9	10	10	12	14	16	18	18	25	28	32	34	34	31	23	20	20	16
	MAY	15	12	9	10	8	9	10	9	11	13	14	15	20	17	25	25	34	38	30	28	26	20	18	14

TACUBAYA

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24 h
1986	JAN	21	16	16	16	14	13	11	10	12	14	18	22	24	27	28	26	26	29	34	35	37	34	28	26
	FEB	20	17	15	11	13	11	9	10	12	15	21	28	34	42	43	46	47	47	44	39	35	34	29	25
	MAR	25	22	21	17	17	16	12	14	14	18	22	28	36	41	42	41	43	51	52	48	44	42	38	31
	APR	27	22	18	15	15	13	10	9	12	17	20	25	30	40	49	50	58	56	49	50	40	36	33	28
	MAY	24	23	21	19	18	18	14	17	19	18	22	26	30	39	43	39	44	48	45	44	37	36	31	25
	JUN	26	27	22	21	18	18	15	17	19	22	23	24	33	37	41	38	45	46	40	35	35	34	34	30
	JUL	31	30	26	23	19	17	17	18	22	22	24	28	31	33	37	42	46	44	46	45	40	40	34	35
	AUG	33	31	28	26	24	21	19	20	24	23	25	28	30	35	43	45	56	51	46	45	42	40	37	37
	SEP	35	31	27	28	26	27	23	27	29	27	27	29	32	36	39	40	43	47	52	48	49	45	40	38
	OCT	26	22	18	17	16	15	17	18	20	25	23	27	28	33	35	37	40	43	43	41	41	39	34	31
	NOV	18	15	13	11	11	10	10	11	13	17	18	21	26	28	31	33	38	38	37	36	35	31	29	25
	DEC	16	13	12	9	10	12	12	10	9	12	16	22	28	32	36	37	38	38	31	28	27	26	23	17

Figure 3.1.7 Speed of Wind with the Most Frequent Monthly-Hourly Direction

(2) Upper Meteorology

1) Outline of the Upper Meteorological Observation

Upper meteorological observation was made four times in each season at the CENTRO No. 5 point, as shown in Table 3.1.4.

Table 3.1.4 Outline of Upper Meteorological Observation

Season	Month, Year	Captive Sonde				Low-level Sonde			Remarks
		Plan		Executed		Plan	Executed		
		Period (days)	Frequency (times)	Frequency (times)	Ratio (%)	Frequency (times)	Frequency (times)	Ratio (%)	
Summer	Sept., 1987	5	40	32	80.0	5	5	100.0	
Autumun	Nov. and Dec., 1987	14	112	101	90.2	14	14	100.0	3-day special observation
Winter	Feb., 1988	7	56	40	71.4	7	7	100.0	2-day special observation
Spring	May, 1988	7	56	40	71.4	7	7	100.0	2-day special observation

2) General Weather During the Observation Period

During the summer period (September 12 - 14 and 17 - 19), it was generally cloudy from evening to morning and less cloudy in the daytime.

During the autumn period (November 19 - December 3), in the first half of the period, some days were fine all day long and the others were fine during daytime and cloudy at night with temporary rain. In the latter half of the period, it was generally cloudy from morning to evening and clear at midnight.

During the winter period (February 17 - 24), it was clear initially followed by some days with cloud in the morning. In the latter half of the period, the weather was generally fine.

During the spring period (May 20 - 27), it was mostly cloudy from midnight to morning with rapid disappearance of cloud as the sun rose, clear from morning to noon, with cloud increasing in the afternoon and thundershowering in the evening.

3) Trend of Wind Direction by Altitute

The wind direction appearance frequency diagram by altitude for whole day, daytime and nighttime over the entire period of the observation is shown in Figure 3.1.8.

The wind roses for whole day indicates frequent appearance of the ENE to E winds and the SW to NW winds on the ground and the E to SSE winds and the W to N winds at altitudes from 50 m to 150 m. At altitudes above 200 m, winds were in all directions and no prevailing wind direction was observed.

The prevailing wind directions in the daytime were E to SSE and NNW to NNE up to the altitude of around 350 m, while above this altitude, the wind direction was various.

The prevailing wind directions in the nighttime were NW to NNW up to the altitude around 150 m, i.e., the wind directions opposite to those in the daytime. At altitudes, above 200 m, the wind direction varies.

Figure 3.1.9 shows the appearance frequency of wind directions and wind speed by altitude at 6:00 and 18:00 at AEROPUERTO from January to December 1986.

At 6:00, appearance of the calm state on the ground and at 200 m was 41 - 52%. At the altitudes of 500 m and 900 m, the N to NNW winds and the SSE to S winds are prevailing. At the altitude of 1400 m, winds are in all directions.

At 18:00, the N to NNW winds and the SE winds are prevailing on the ground and at the altitudes of 200 m and 500 m, and the N to NW winds prevailing at 900 m and 1400 m.

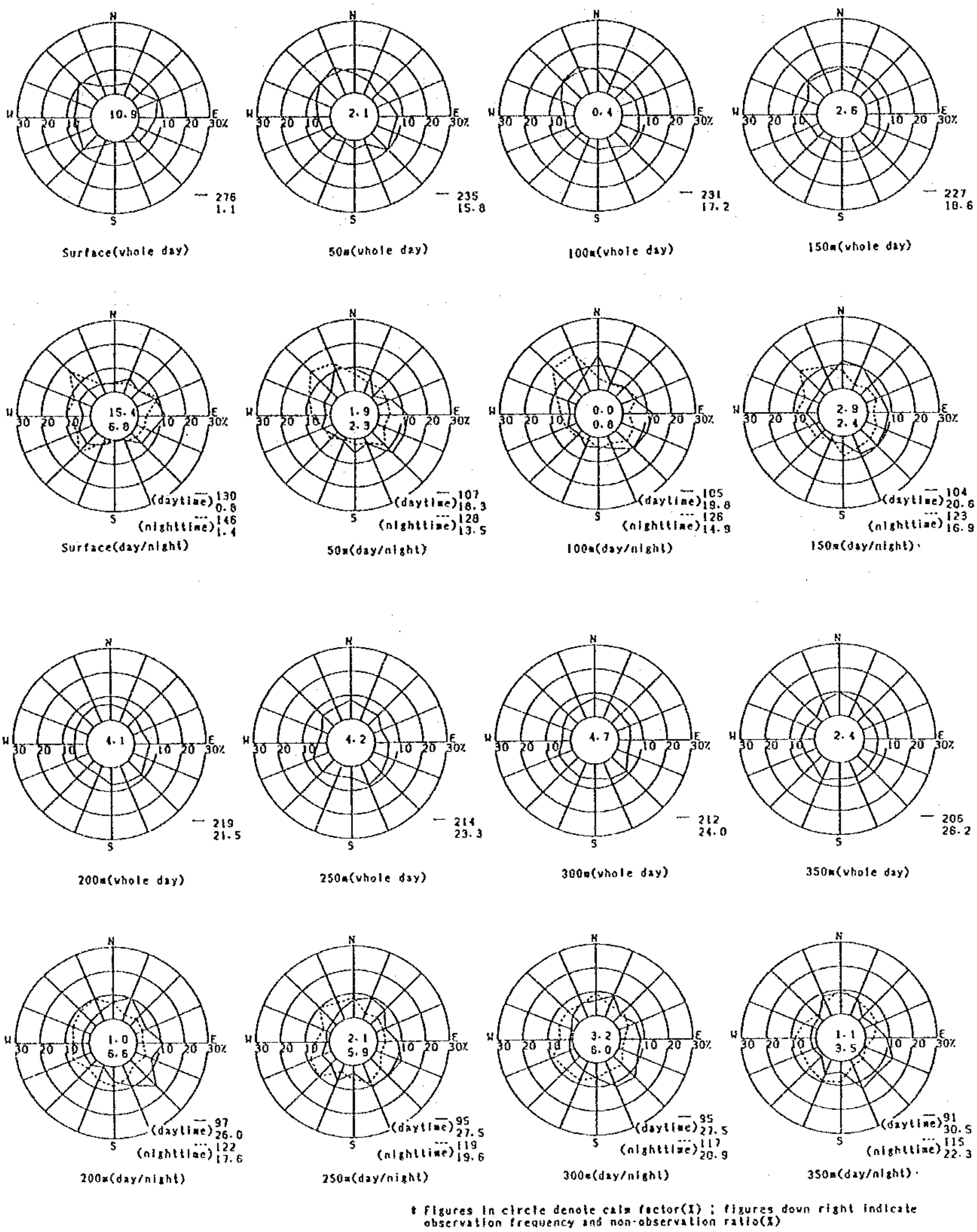
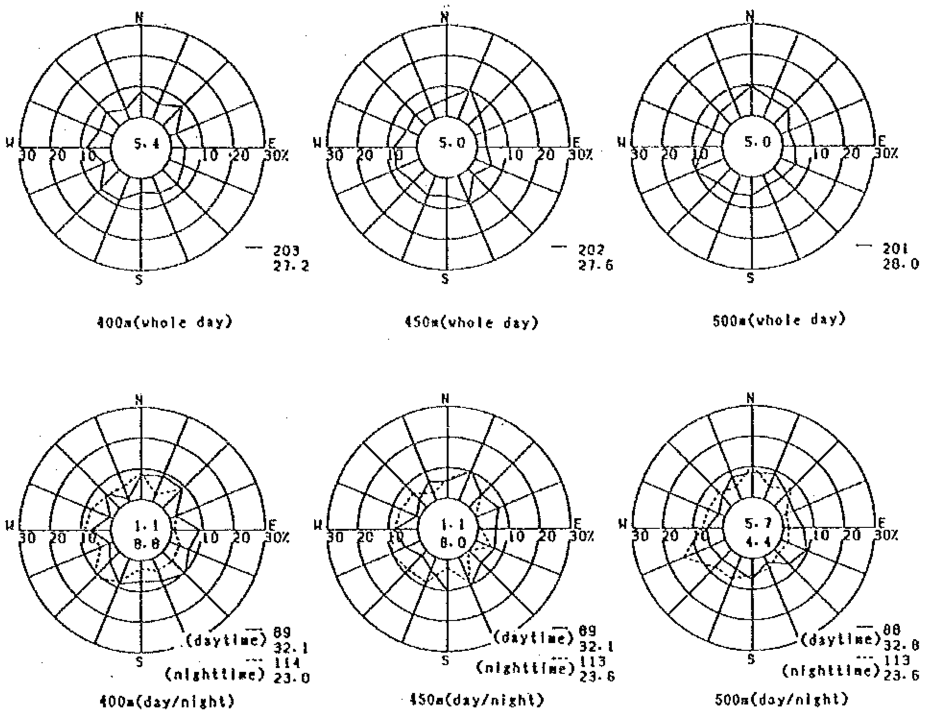


Figure 3.1.8 (1) Wind Direction Appearance Frequency by Altitude
Location: Centro No.5
Period: Sept., 1987 to May, 1988



* Figures in circle denote calm factor(%) ; figures down right indicate observation frequency and non-observation ratio(%)

Figure 3.1.8 (2) Wind Direction Appearance Frequency by Altitude
Location: Centro No.5
Period: Sept., 1987 to May, 1988

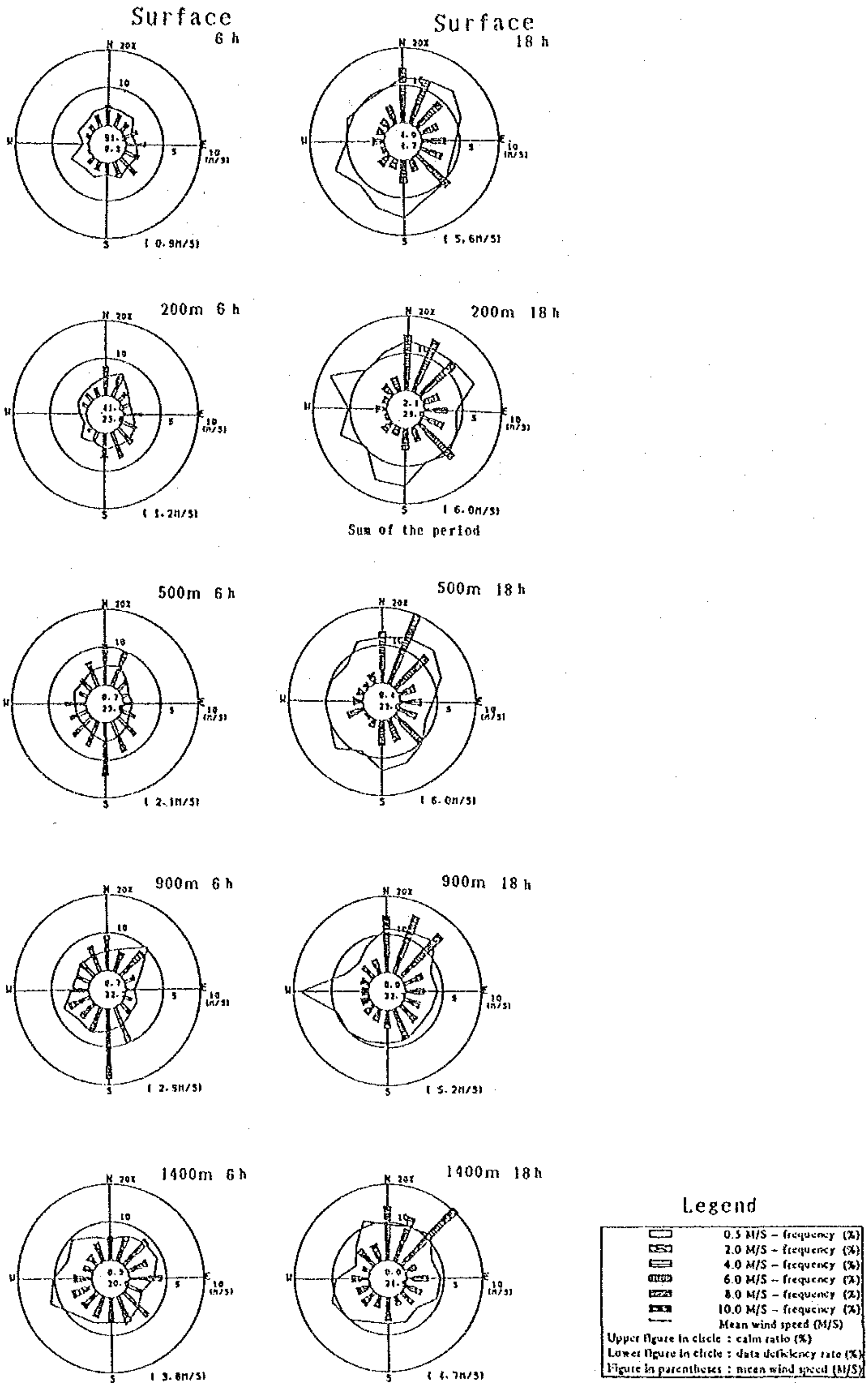
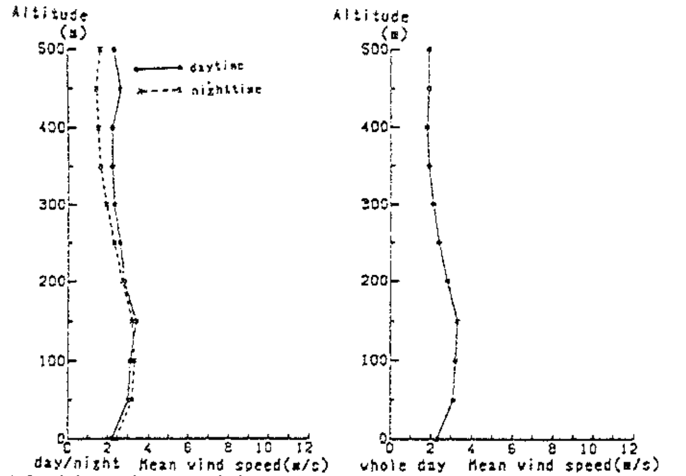


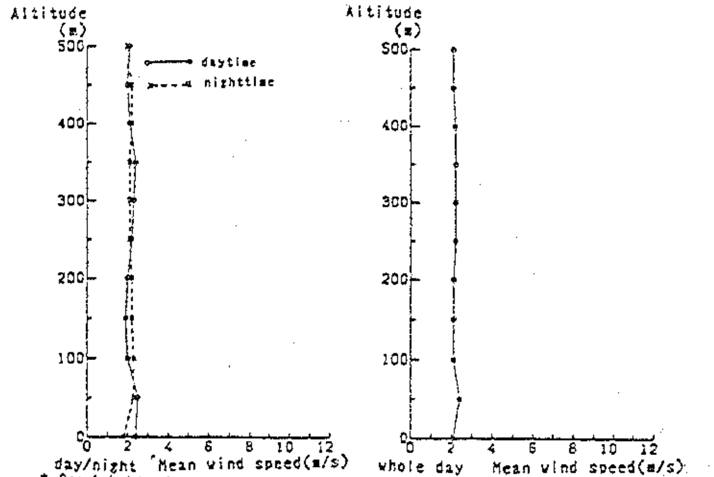
Figure 3.1.9 Appearance Frequency of Wind Direction and Wind Speed by Altitude
Location: AEROPUERTO
Period: Jan. to Dec., 1986

4) Mean Wind Speed by Altitude

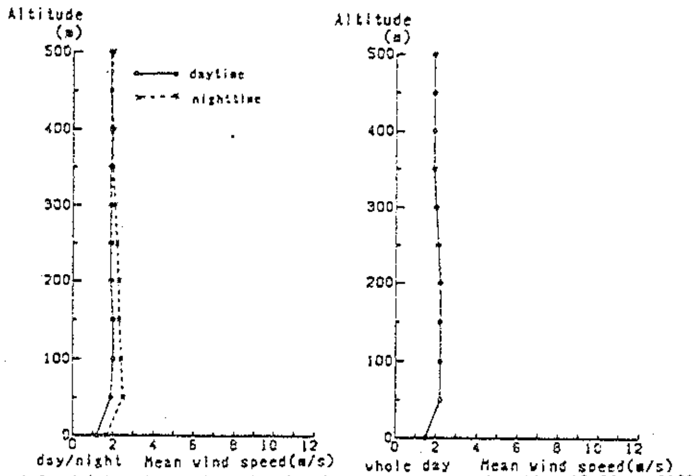
Figure 3.1.10 (1) shows the mean wind speed by altitude at CENTRO No. 5 for each season and Figure 3.1.10 (2) for the entire period. Since the captive sonde was used to measure the vertical distribution of wind speed, difficulty in measurement increased at 15:00 -21:00 when the wind speed was high.
As a result, the mean wind speed at these hours seemed to be slightly lower.
For the entire period, the whole day mean wind speed was lowest at 1.8 m/s on the ground, and highest at 2.4 m/s at 50 -100 m above ground. For the altitude range from 150 -300 m, mean wind speed decreased gradually with increasing altitude until it reached 2.0 m/s above 300 m. This trend is similar both in daytime and nighttime being mean wind speed highest at altitudes of 50 - 100 m. The speed at this altitude in the nighttime was slightly higher than that in the daytime.
In the summer, the wind speed was highest at altitudes of 100 - 150 m, with considerable difference altitude. Such difference was small in all other seasons.
Figure 3.1.11 shows the vertical distribution of wind speed at AEROPUERTO at 6:00 and 18:00 from January to December 1986.
At 6:00, the wind speed was lowest on the ground and increased with increasing altitude. The vertical profile at 18:00 was different from that at 6:00, with the wind speed highest at the altitudes of 200 - 500 m.



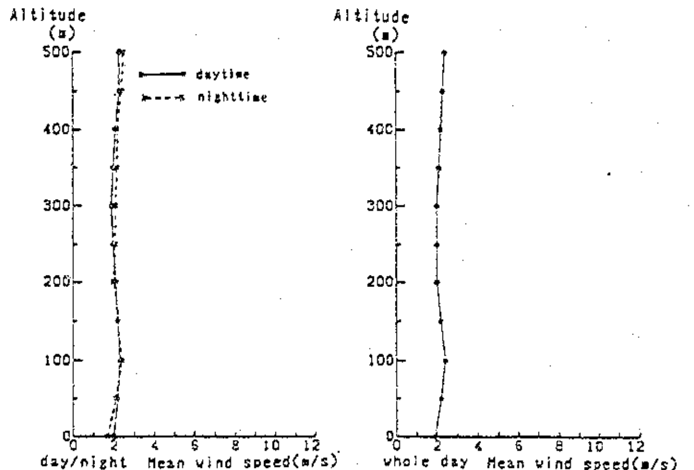
* Day/night time zone : daytime=7:00 to 18:00 ; nighttime=19:00 to 6:00
Period : September, 10~19 1987



* Day/night time zone : daytime=8:00 to 18:00 ; nighttime=19:00 to 7:00
Period ; February 17~24, 1988



* Day/night time zone : daytime=7:00 to 17:00 ; nighttime=18:00 to 6:00
Period; November,19~December ,3 1987



* Day/night time zone : daytime=7:00 to 19:00 ; nighttime=20:00 to 6:00
Period; May, 20~27 1988

Figure 3.1.10 (1) Mean Wind Speed by Altitude in Each Season (Location: CENTRO No. 5)

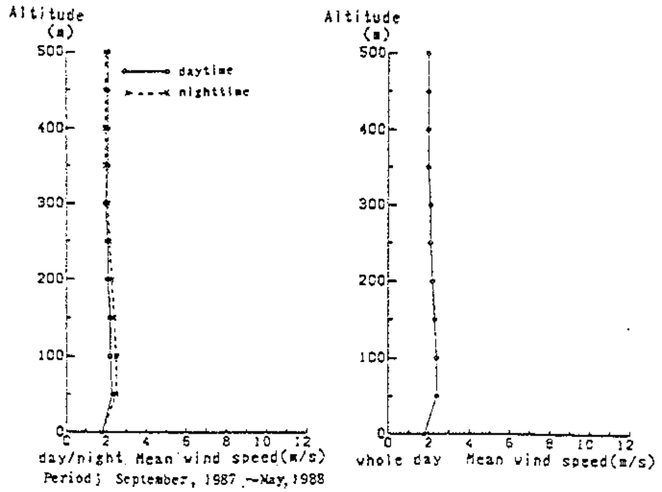


Figure 3.1.10 (2) Mean Wind Speed by Altitude for the Whole Period
(Location: CENTRO No. 5)

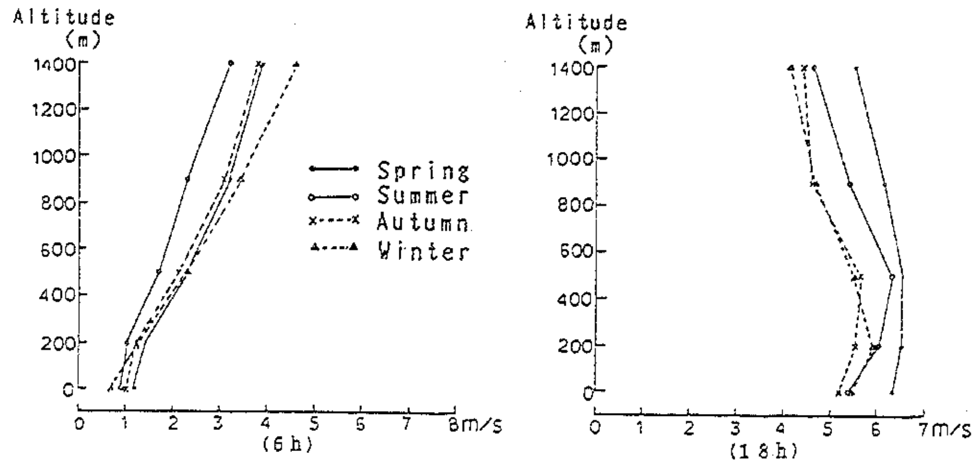


Figure 3.1.11 Mean Wind Speed by Altitude
(Location: AEROPUERTO,
Period: Jan. - Dec. 1986)

5) Vertical Profile of Air Temperature

Figure 3.1.12 shows the time-course change of typical vertical air temperature profile at CENTRO No. 5 during the days with or without the surface level inversion of air temperature. The surface inversion was observed on one day for one hour in the summer observation period. In other seasons, occurrence was 57 - 86% of the observation days and lasted longer. The surface inversion usually occurred at around 21:00 at altitudes below 50 m. By the sunrise, the temperature difference between top and bottom of the inversion layer and its thickness increased. Then, the layer began disappearing from the bottom.

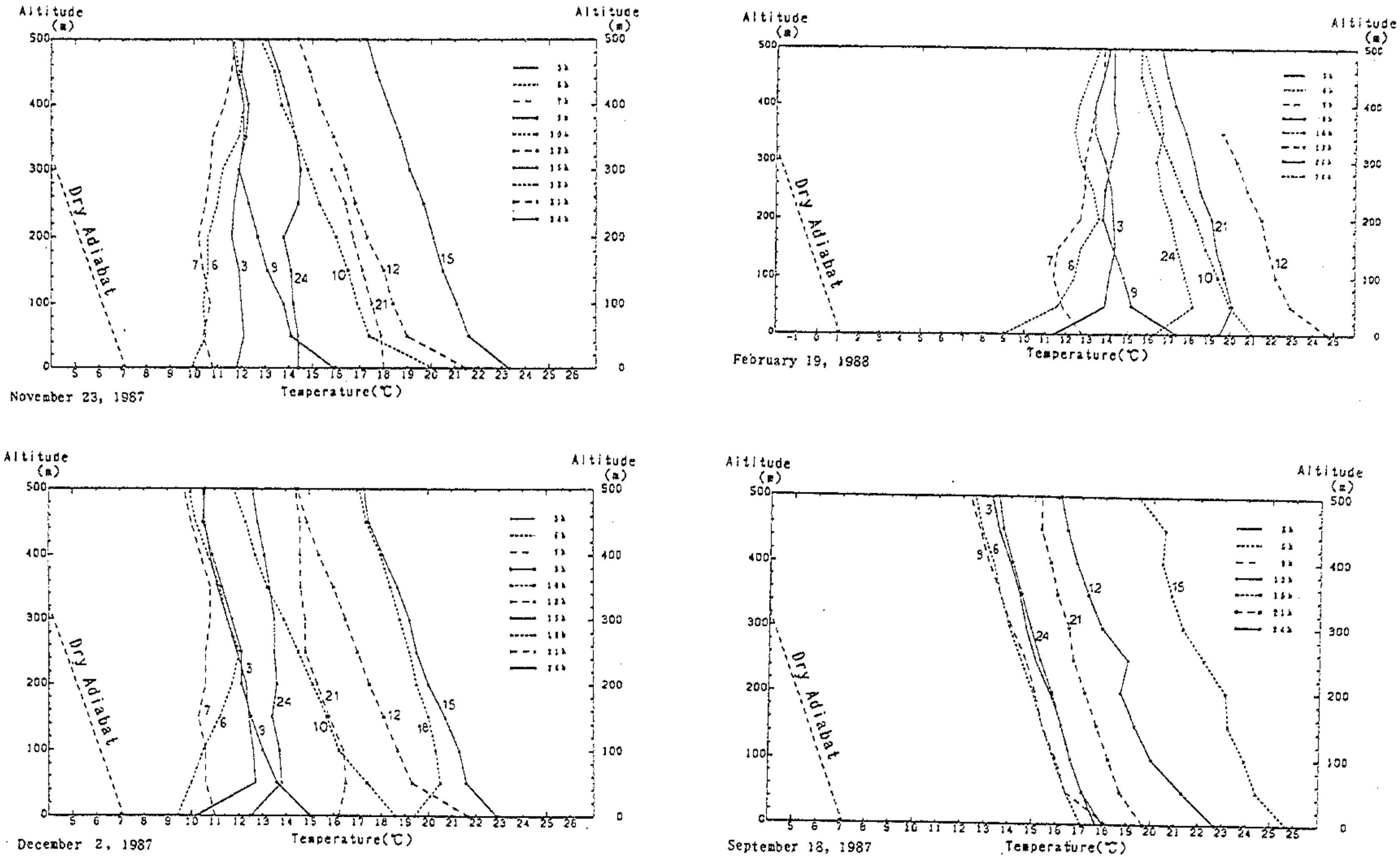


Figure 3.1.12 Time-Course Change of Vertical Air Temperature Profile
(with captive sonde lowering)
Location: CENTRO No. 5

6) Temperature Gradient by Altitude

Figure 3.1.13 shows the air temperature gradient by altitude at CENTRO No. 5 for whole day, daytime, and nighttime averaged over the observation period.

In the daytime, the layer below 50 m was unstable due to the influence of solar radiation, and air stability above this altitude was transient from neutral state to slightly stable state. In the nighttime, the 0 - 50 m layer showed the inversion state due to radiation cooling and the upper layer showed stable state.

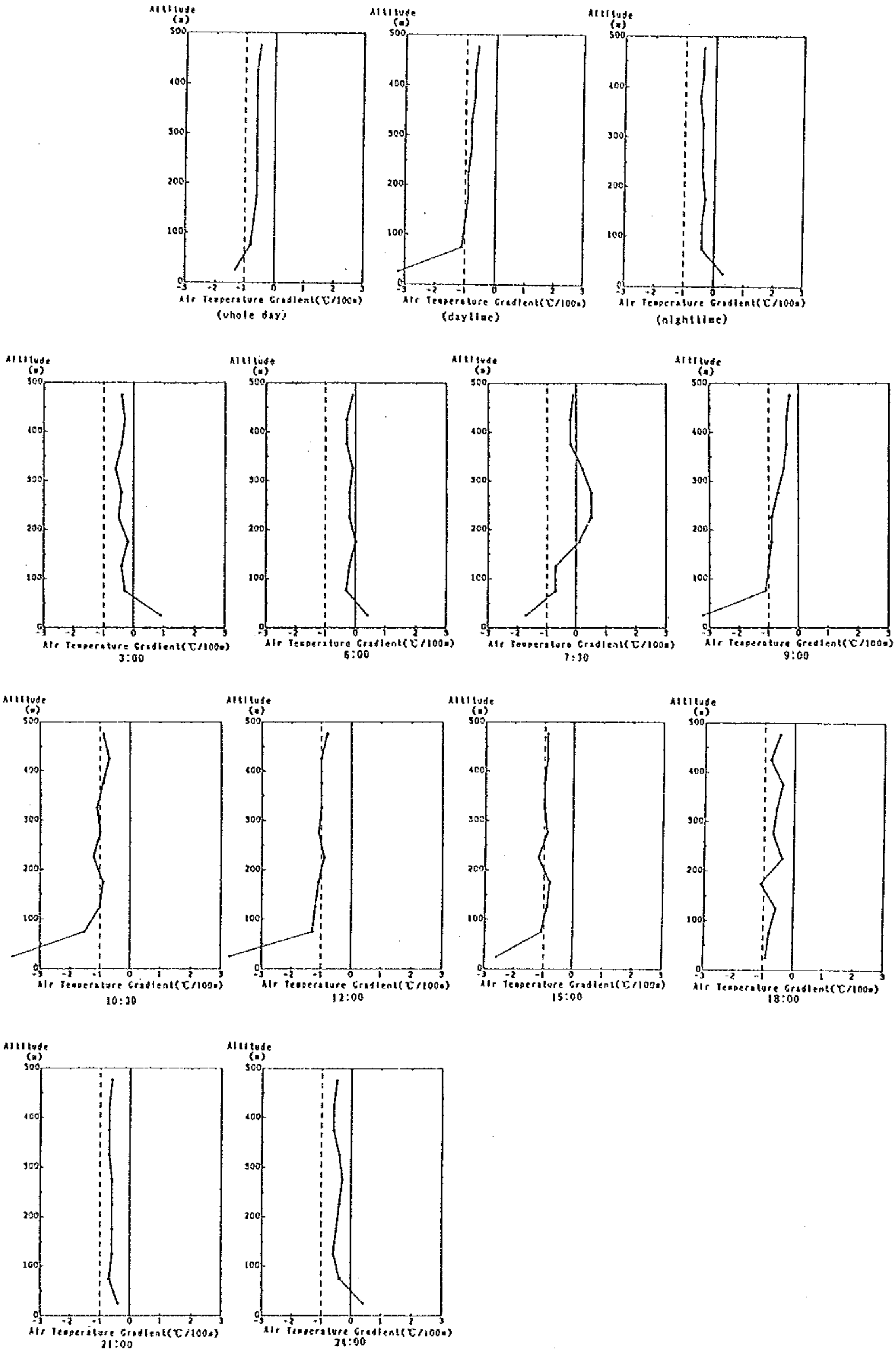


Figure 3.1.13 Air Temperature Gradient by Altitude
(with captive sonde lowering)
Location: CENTRO No. 5
Period: Sept. 1987 to May 1988

7) Frequency of Appearance of Temperature Gradient

Figure 3.1.14 shows the air temperature gradient appearance by altitude for whole day, daytime, and nighttime over the observation period.

In the daytime, appearance of the unstable state at -0.8°C/100 m occupied the high percentage of 87% for the layer at 0 - 50 m due to the effect of solar radiation. For all layers above 50 m, appearance of the neutral state at -1.2 to -0.8°C/100 m was highest at 39 - 73%. The inversion state appeared at around 10% to 20% in each layer from 200 - 500 m. This indicates that the upper level inversion and advective inversion are apt to appear in layers above 200 m with the disappearance of surface inversion.

In the nighttime, inversion state at 0.0°C/100 m or more appeared at about 50% in the layer at 0 - 50 m due to the effect of radiation cooling on the ground surface. For the layer above 50 m, the neutral to slightly stable state at -1.2 to -0.3 °C/100 m appeared at around 70%.

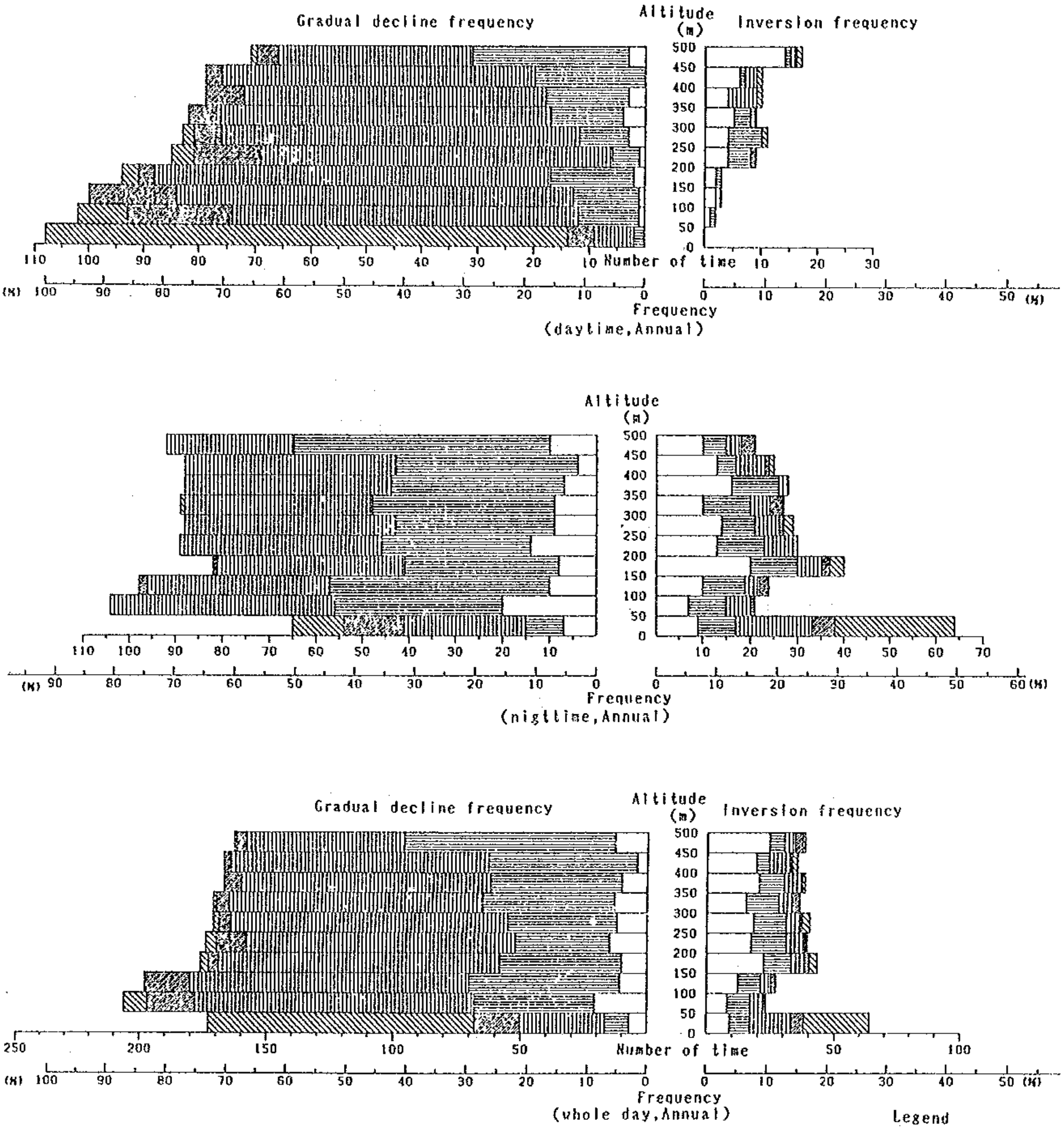
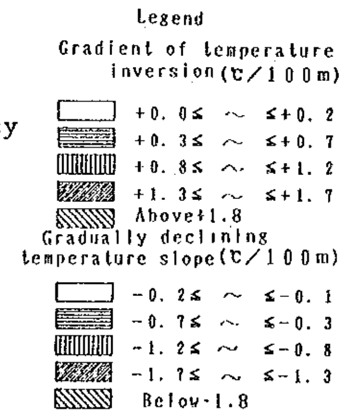


Figure 3.1.14 Air Temperature Gradient Appearance Frequency (with captive sonde lowering)
Location: CENTRO No. 5
Period: Sept. 1987 to May 1988



8) State of Appearance of Thermal Inversion Layer

The surface air temperature inversion occurred in one of four nights in summer, in 12 of 14 nights in autumn, four of seven nights in winter, and five of seven nights in spring.

The surface inversion appeared with a high frequency for the period of 21:00 to 3:00. Disappearance of surface inversion began after 6:00, upper inversion remained at 9:00, and no inversion remained in all layers at 12:00.

Table 3.1.5 shows the thickness of surface inversion layer and air temperature difference while Table 3.1.6 (1) and (2) the top altitude, bottom altitude, thickness, and air temperature difference between top and bottom for upper level inversion.

The thickness of the surface inversion layer of 50 m had a greatest frequency of occurrence with 41 times among 64 occurrences over the entire observation period, and 4 to 6 times in each thickness in the range of 100 - 250 m. The maximum thickness was 400 m in autumn. The most frequent air temperature difference was 1.0°C or less. The difference exceeding 3.1°C was rare.

The upper level inversion occurred 128 times during the entire observation period. The most frequent bottom altitude was 150 m (24 times), followed by 200 m (19 times), and 350 m (18 times). The most frequent top altitude was 500 m or more (34 times), followed by 200 m (18 times). The most frequent thickness was 50 m (70 times, about one half of the total), but the thickness seldom exceeded 250 m. The most frequent air temperature difference was 0.0 -0.5°C (101 times).

Table 3.1.5
Thickness and Temperature Difference of Surface Inversion

Thickness (m)	Summer	Autumn	Winter	Spring	Total
0～ 50	1	28	7	5	41
0～100		4	1	1	6
0～150		1	1	2	4
0～200		3	1		4
0～250		2	2	1	5
0～300		1	1		2
0～350					
0～400		2			2
Total	1	41	13	9	64
Times of observation	34	114	47	44	239

Temperature difference (℃)	Summer	Autumn	Winter	Spring	Total
0.0～0.5	1	14		4	19
0.6～1.0		15	4	1	20
1.1～1.5		5	3	1	9
1.6～2.0		3	3	2	8
2.1～3.0		4	2	1	7
3.1～4.0					
4.1～			1		1
Total	1	41	13	9	64
Times of observation	34	114	47	44	239

Table 3.1.6 (1)
Top and Bottom Altitudes of Upper Level Inversion

Bottom altitude (m)	Summer	Autumn	Winter	Spring	Total
50	1	4	3	1	9
100	2	4	1	2	9
150	1	14	5	4	24
200	2	10	5	2	19
250	1	8		3	12
300	1	6	3	2	12
350		10	6	2	18
400	1	3	4	4	12
450	3	4	4	2	13
Total	12	63	31	22	128
Times of observation	34	114	47	44	239

Upper altitude (m)	Summer	Autumn	Winter	Spring	Total
100	1	1	2	1	5
150	2	4		1	7
200	1	11	2	4	18
250	1	7	2		10
300	1	8	1	2	12
350	1	5	3	3	12
400	1	8	5	2	16
450	1	6	1	6	14
500以上	3	13	15	3	34
Total	12	63	31	22	128
Times of observation	34	114	47	44	239

Table 3.1.6 (2)
Thickness and Temperature Difference of Upper Level Inversion

Thickness (m)	Summer	Autumn	Winter	Spring	Total
0～ 50	10	34	14	12	70
0～100	1	12	4	7	24
0～150	1	9	5	2	17
0～200		5	5	1	11
0～250		1			1
0～300		2	1		3
0～350			1		1
0～400			1		1
Total	12	63	31	22	128
Times of observation	34	114	47	44	239

Temperature difference (℃)	Summer	Autumn	Winter	Spring	Total
0.0～0.5	12	51	19	19	101
0.6～1.0		5	4	2	11
1.1～1.5		6	3	1	10
1.6～2.0			2		2
2.1～3.0		1	3		4
3.1～4.0					
4.1～					
Total	12	63	31	22	128
Times of observation	34	114	47	44	239

The inversion thickness and air temperature difference observed at AEROPUERTO at 6:00 are shown in Figure 3.1.15 and Table 3.1.7.

Monthly appearance frequency of the surface inversion was four to five days in June to September (rainy season) and 16 -28 days (more than half a month) in October to May (dry season). A thickness of 200 m or less occurred at 64% (about 2/3), but about 10% of the days of November to April showed the thickness of 500 m or more. The appearance of air temperature difference of 2.0°C or less was 47% (about one half) while the appearance of higher classes (4.1°C or more) was 26% in November to April.

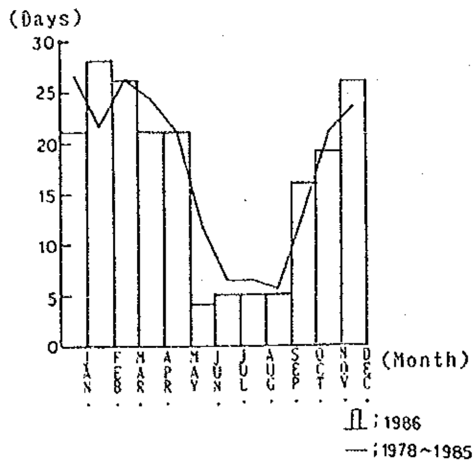


Figure 3.1.15 Monthly Appearance of Surface Inversion (Location: AEROPUERTO)

Table 3.1.7 (1) Surface Inversion Appearance Frequency of Thickness
Location: AEROPUERTO, 6:00
Period: Jan. to Dec. 1986
Unit: Thickness (m), frequency (times)

Thickness	1 50	51 100	101 150	151 200	201 250	251 300	301 350	351 400	401 450	451 500	501 600	601 700	701 800	801 900	901 1000	1001 5000	Total	No Inversion	No Observation
Jan.	0	4	2	1	2	3	1	1	0	2	1	3	1	0	0	0	21	7	3
Feb.	0	6	8	6	1	0	0	4	2	0	0	1	0	0	0	0	28	0	0
Mar.	0	6	8	5	2	2	0	2	0	0	1	0	0	0	0	0	26	5	0
Apr.	1	5	3	7	2	1	0	0	0	0	2	0	0	0	0	0	21	9	0
May	0	3	8	3	2	2	2	1	0	0	0	0	0	0	0	0	21	10	0
Jun.	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	4	26	0
Jul.	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	0
Aug.	0	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	5	25	1
Sep.	0	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	5	23	2
Oct.	0	2	6	6	0	2	0	0	0	0	0	0	0	0	0	0	16	15	0
Nov.	0	2	3	5	1	0	1	1	1	2	2	1	0	0	0	0	19	10	1
Dec.	0	2	2	6	0	3	0	2	1	3	3	1	0	1	1	1	26	5	0
Spring	1	14	19	15	6	5	2	3	0	0	3	0	0	0	0	0	68	24	0
Summer	0	7	5	1	1	0	0	0	0	0	0	0	0	0	0	0	14	77	1
Autumn	0	6	10	12	1	3	1	1	1	2	2	1	0	0	0	0	40	48	3
Winter	0	12	12	13	3	6	1	7	3	5	4	5	1	1	1	1	75	12	3
Year	1	39	45	41	11	14	4	11	4	7	9	6	1	1	1	1	197	161	7

Table 3.1.7 (2) Surface Inversion Appearance Frequency by Air Temperature Difference
Location: AEROPUERTO, 6:00
Period: Jan. to Dec. 1986
Unit: Temperature difference (0.1°C), frequency (times)

Temperature	1 10	11 20	21 30	31 40	41 50	51 60	61 70	71 80	81 90	91 100	101 500	Total	No Inversion	No Observation
Jan.	1	2	2	6	1	4	3	2	1	0	0	22	7	2
Feb.	4	3	3	5	5	3	4	1	0	0	0	28	0	0
Mar.	2	3	3	4	7	5	0	0	0	0	0	26	5	0
Apr.	2	6	5	5	1	2	0	0	0	0	0	21	9	0
May	8	8	3	1	0	1	0	0	0	0	0	21	10	0
Jun.	3	1	0	0	0	0	0	0	0	0	0	4	26	0
Jul.	5	0	0	0	0	0	0	0	0	0	0	5	26	0
Aug.	4	1	0	0	0	0	0	0	0	0	0	5	25	1
Sep.	5	0	0	0	0	0	0	0	0	0	0	5	23	2
Oct.	10	6	0	0	0	0	0	0	0	0	0	16	15	0
Nov.	7	4	0	3	1	2	2	0	0	0	0	19	10	1
Dec.	1	4	9	6	2	3	0	0	1	0	0	24	5	2
Spring	12	19	11	10	8	8	0	0	0	0	0	68	24	0
Summer	12	2	0	0	0	0	0	0	0	0	0	14	77	1
Autumn	22	10	0	3	1	2	2	0	0	0	0	40	48	3
Winter	6	9	14	15	8	10	7	3	2	0	0	74	12	4
Year	52	40	25	28	17	20	9	3	2	0	0	196	161	8

9) Vertical Profile of Air Temperature Observed With Low-level Sonde

Figures 3.1.16 (1) and (2) show the typical vertical air temperature profiles as observed with low-level sonde at CENTRO No. 5.

At 13:30, the upper level inversion appeared 8 times out of the total 33 observations. Two of these (December 3 and February 21) appeared at the altitude range from 1100 to 1700 m. The remaining 25 appearances included the temperature gradient higher than the dry adiabatic lapse rate from ground to around 50 m, and above this altitude, the temperature gradient was nearly equal to the dry adiabatic lapse rate.

Comparison of the vertical air temperature profile between 7:30 or 10:30 and 13:30 in Figure 3.1.16 (2) shows that the temperature difference with time was small in the upper layer and large in the lower layer. In the lower zone at 7:30 and 10:30, inversion and isothermal layers are seen, while the upper zone showed a stable stratification. The vertical temperature distribution at 13:30 indicated air temperature gradient nearly equal to the dry adiabatic lapse rate over the entire zone.

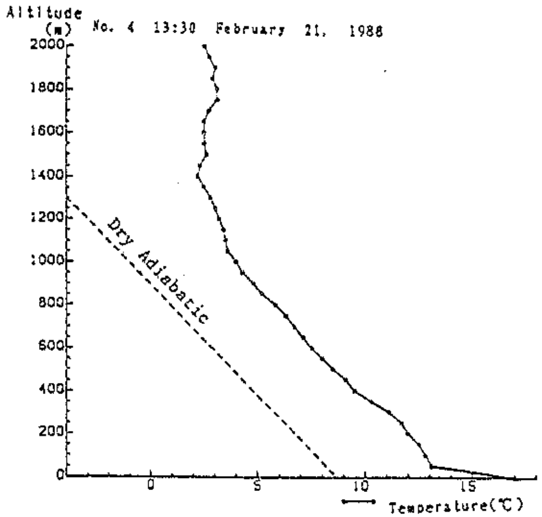


Figure 3.1.16 (1) Vertical Air Temperature Profile for a Day with Remarkable Upper Level Inversion (by low-level sonde)
Location: CENTRO No. 5

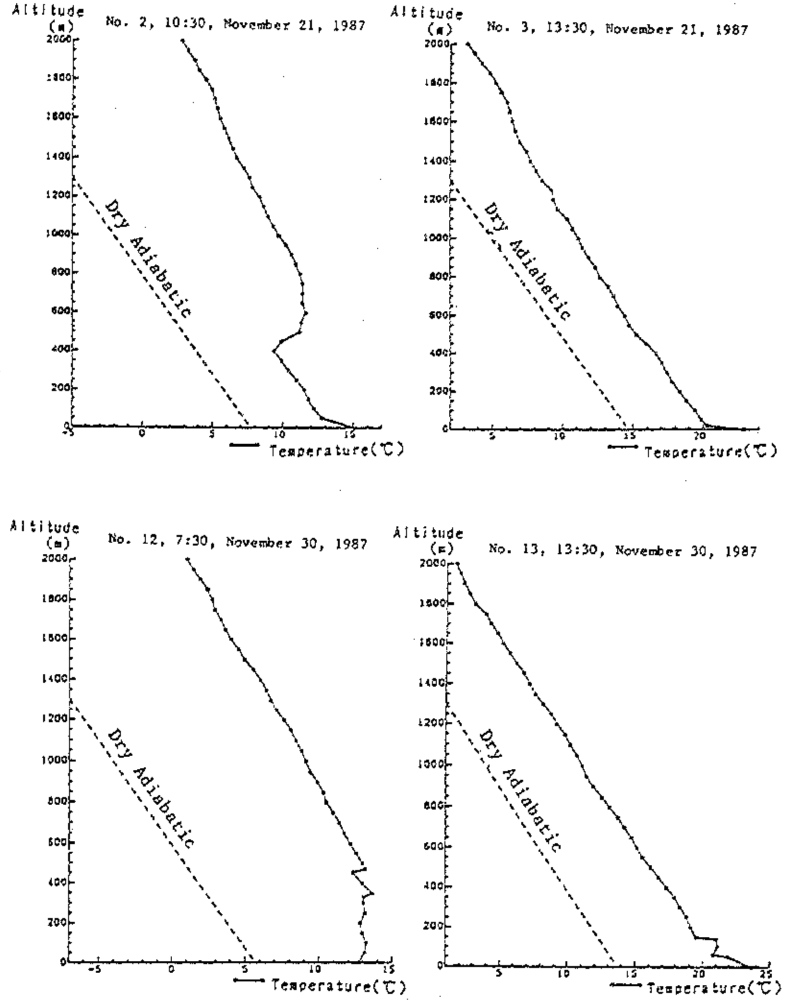


Figure 3.1.16 (2) Vertical Air Temperature Profile in the Morning and the Afternoon (by low-level sonde)
Location: CENTRO No. 5

3.2 Measurement of Ambient Air Quality

The outline of field measurements of ambient air quality conducted in this study is shown in Table 3.2.1.

Table 3.2.1 Outline of Ambient Air Quality Measurements

Classification of Measurement	Items	Method
Long-term measurement at fixed stations	Nitrogen oxides (NO, NO_2, NOx)	Continuous measurement at one fixed station in the City
	TSP concentration and metallic element analysis	Monthly measurement of concentration of TSP and metallic elements by particle size at five stations in and around the City
Measurements using monitoring cars	Sulfur dioxide (SO_2) Nitrogen oxides (NO, NO_2, NOx) Carbon monoxide (CO) Suspended particulate matter (SPM) Non-methane hydrocarbons (NMHC) Ozone (O_3) Wind direction and speed (WD, WS)	Measurement at roadside and off-road points using two monitoring cars Two points per month
Simplified measurement	Nitrogen oxides (NO_2, NOx)	Measurements made twice at each of 12 principal crossings in the City

3.2.1 Items and Methods

(1) Measurement of Nitrogen Oxides at the Fixed Station

Measuring instrument was installed on the fourth floor of the DDF office building located as shown in Figure 3.2.1 and concentration of nitrogen oxides (NO, NO_2, NOx) measured.

The schedule for the measurement is shown in Table 3.2.2, and specifications of equipment used and the names of measuring points are shown in the Appendices.

Table 3.2.2 Schedule for Measurement of Nitrogen Oxides at Fixed Station

Measuring Point	Item	Method	Period
OFICINA CENTRAL DE DDF 4F	Nitrogen oxides (NO, NO_2, NOx)	Continuous measurement with automatic measuring instrument (Chemillumine-scenece)	Sept. 1987 - Aug. 1988

(2) Measurement with Monitoring

Measurements were taken at 19 points shown in Figure 3.2.2. Two monitoring cars were used for monthly measurements at two points at roadside and off-road.

Actual measurement was made for approximately 20 days a month, with the remaining 10 days allocated to travel, preparation, servicing, and standardization. The schedule for the measurement is shown in Table 3.2.3, and specifications of equipment used and the names of measuring points are given in the Appendices.

(3) Measurement of TSP and Metallic Elements

Measuring instruments were installed at the five stations in the city as shown in Figure 3.2.3. The schedule for the measurement is shown in Table 3.2.4, and specifications of equipment used, the names and the addresses of the stations, and the flow chart for the analysis of metallic elements are included in the Appendices.

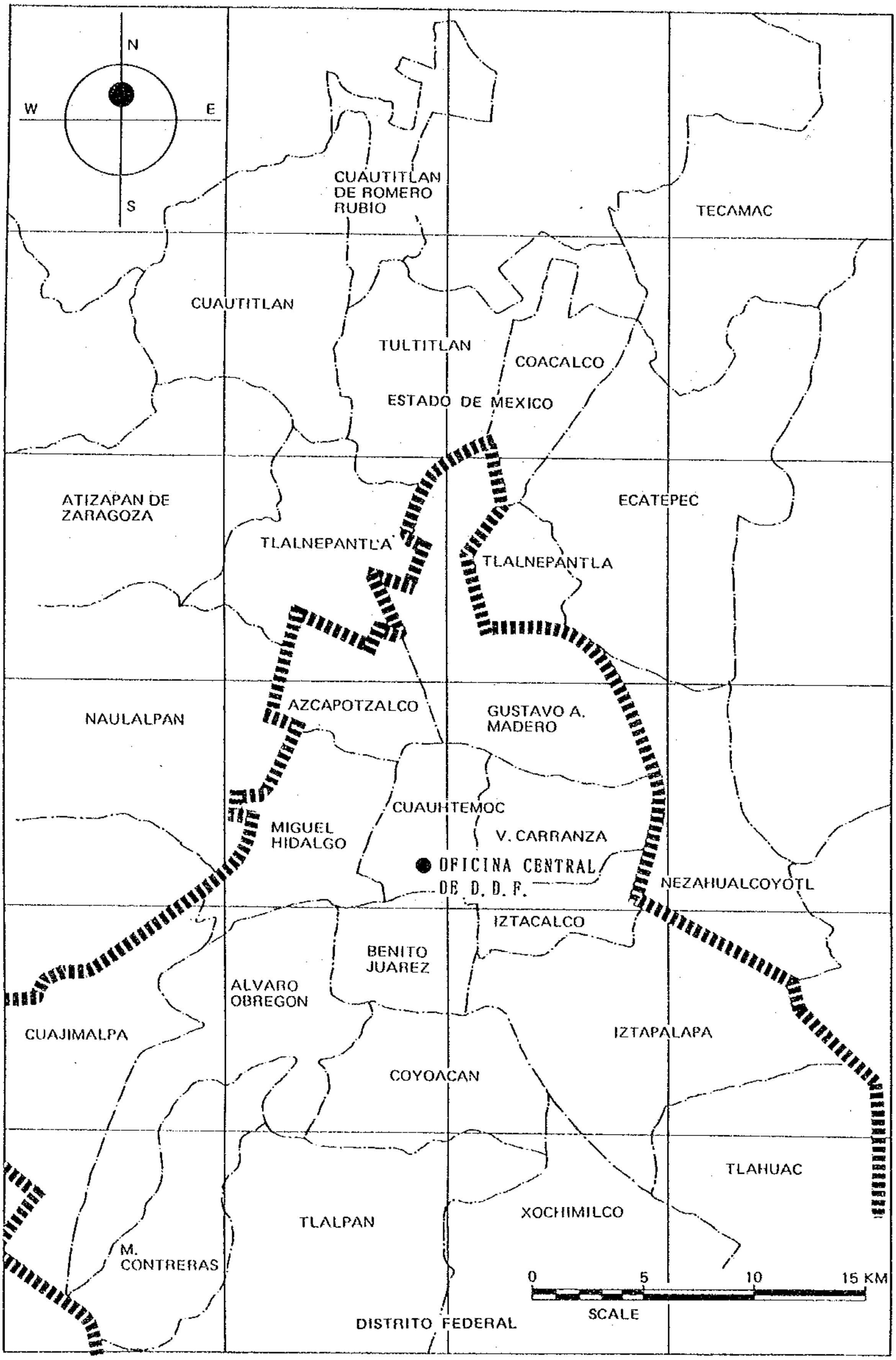


Figure 3.2.1 Location of Continuous Measurement of Nitrogen Oxides

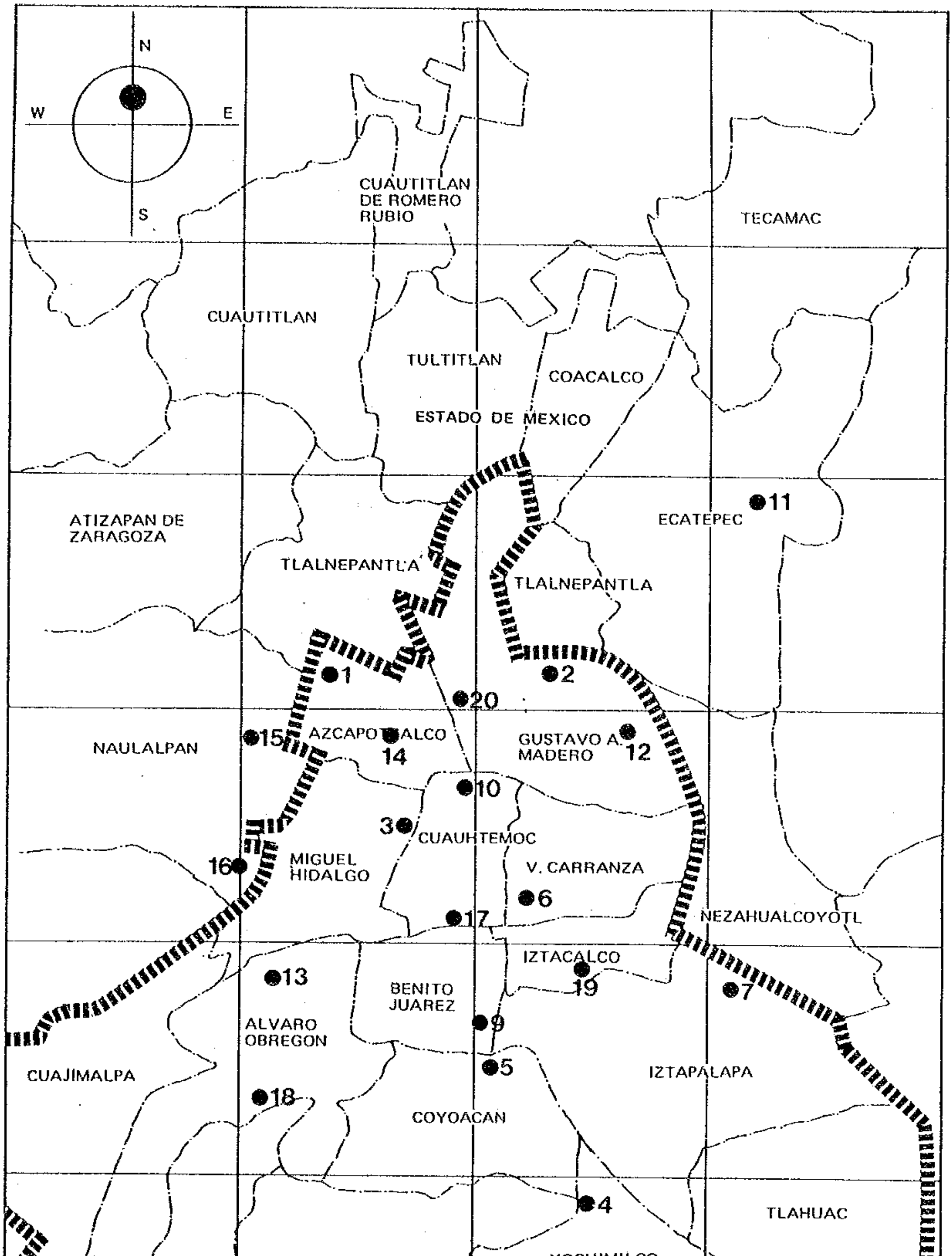


Figure 3.2.2 Location of Measurement by Monitoring Cars

Table 3.2.3 Schedule for Measurement with Monitoring Cars

Items	Method	Period
Sulfur dioxides (SO_2)	Continuous measurement with automatic measuring instrument (UV fluorescence method)	Dec. 1987 to Sep. 1988 (one month per point)
Nitrogen oxides (NO, NO_2, NOx)	Continuous measurement with automatic measuring instrument (Chemilluminescence method)	
Carbon monoxide (CO)	Continuous measurement with automatic measuring instrument (Non-dispersive infra-red absorption method)	
Suspended particulate matter (SPM)	Continuous measurement with automatic measuring instrument (Beta-ray absorption method)	
Non-methane hydrocarbons (NMHC)	Continuous measurement with automatic measuring instrument (Direct gas chromatography)	
Ozone (O_3)	Continuous measurement with automatic measuring instrument (UV absorption method)	
Wind direction/speed (WD, WS)	Continuous measurement with automatic measuring instrument (Three-cup anemometer and wind vane)	

Table 3.2.4 Schedule for Measurement of TSP and Metallic Elements by Particle Size

Item	Method	Period
TSP concentration by particle size	Sampling by Andersen high volume air sampler and gravimetric analysis	Once per month (3 days) for the period from Sept. 1987 to Aug. 1988
Metallic elements by particle size (Fe, Zn, Ni, Pb, V, Mn Na, Ca, K, Al)	Analysis using the atomic absorption spectro-photometer for five particle size classes at one measuring point and for two particle size classes at four measuring points.	

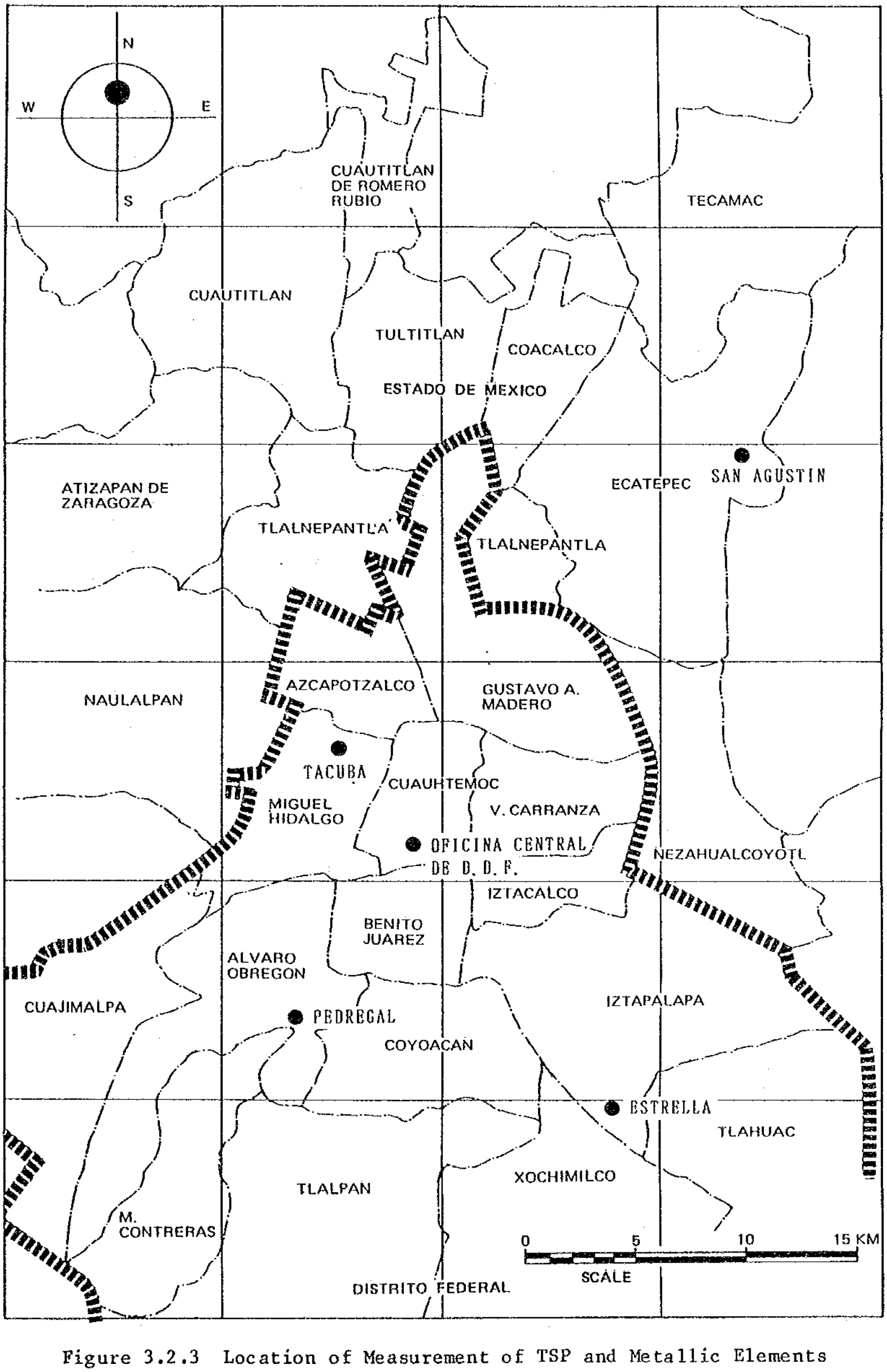


Figure 3.2.3 Location of Measurement of TSP and Metallic Elements

(4) Simplified Measurement

Measurement of nitrogen oxides (NO_2, NO_x) by the simplified method was made at principal crossings in the city as shown in Figure 3.2.4. The schedule for the measurement is shown in Table 3.2.5, and specifications of equipment used, the names of the measuring points, and the analytical flow chart are included in the Appendices.

Table 3.2.5 Schedule for Simplified Measurement of Nitrogen Oxides

Item	Method	Period
Nitrogen oxides (NO_2, NO_x)	Measurement of NO_2 and NO_x conducted using a diffusion sampler. Twelve principal crossings were selected and 50 points were chosen for each crossing.	Oct. 1987 - June 1988 Twice per crossing (48-hour value)

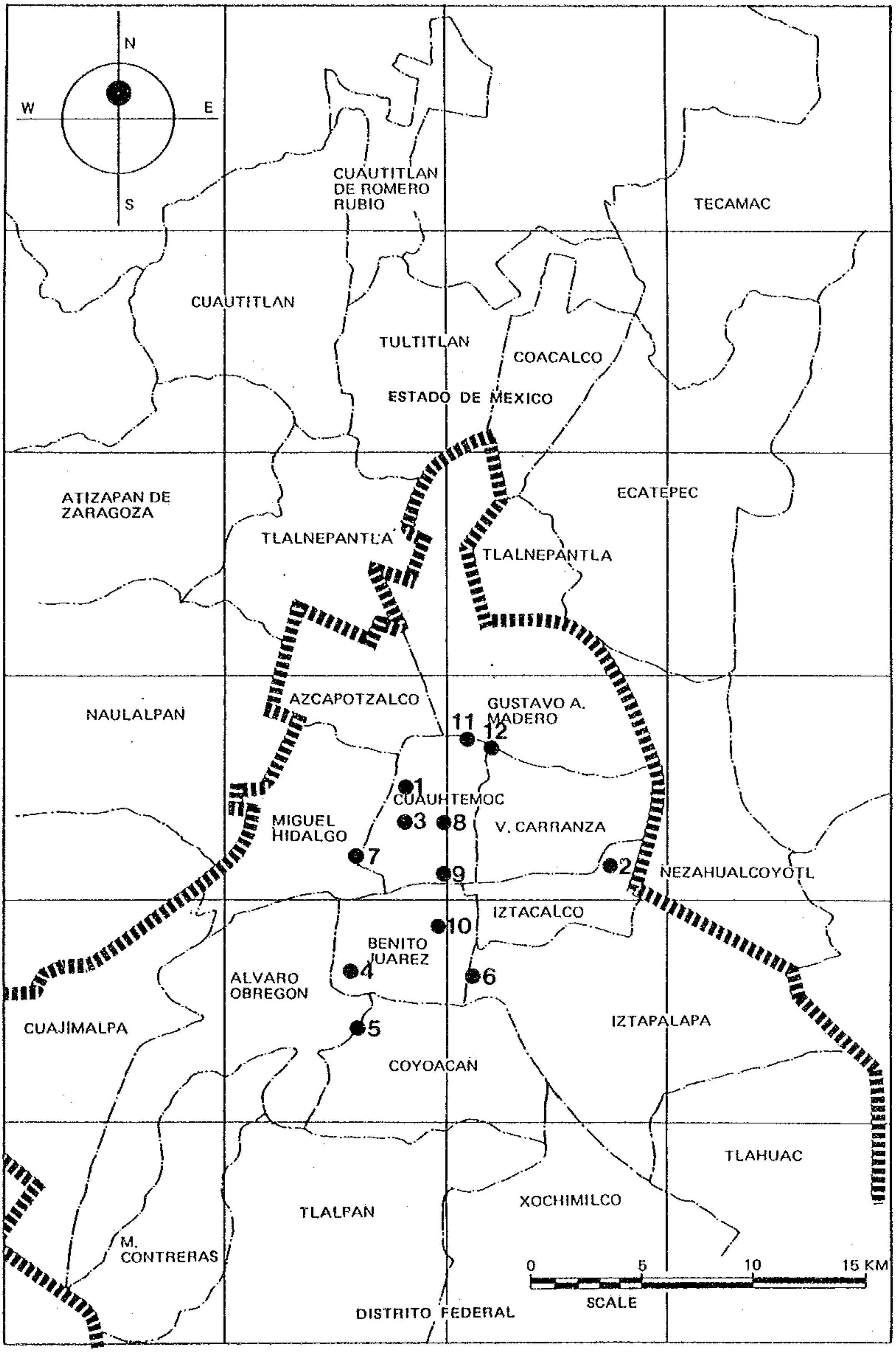


Figure 3.2.4 Location of Crossings for Simplified Measurement of Nitrogen Oxides