Future Challenges in Automobile and Fuel Technologies
For a Better Atmospheric Environment

Air Modeling WG Report

September 25, 2000

JCAP Atmospheric Model WG
Satoshi Yamazaki

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Purpose of Air Modeling Study

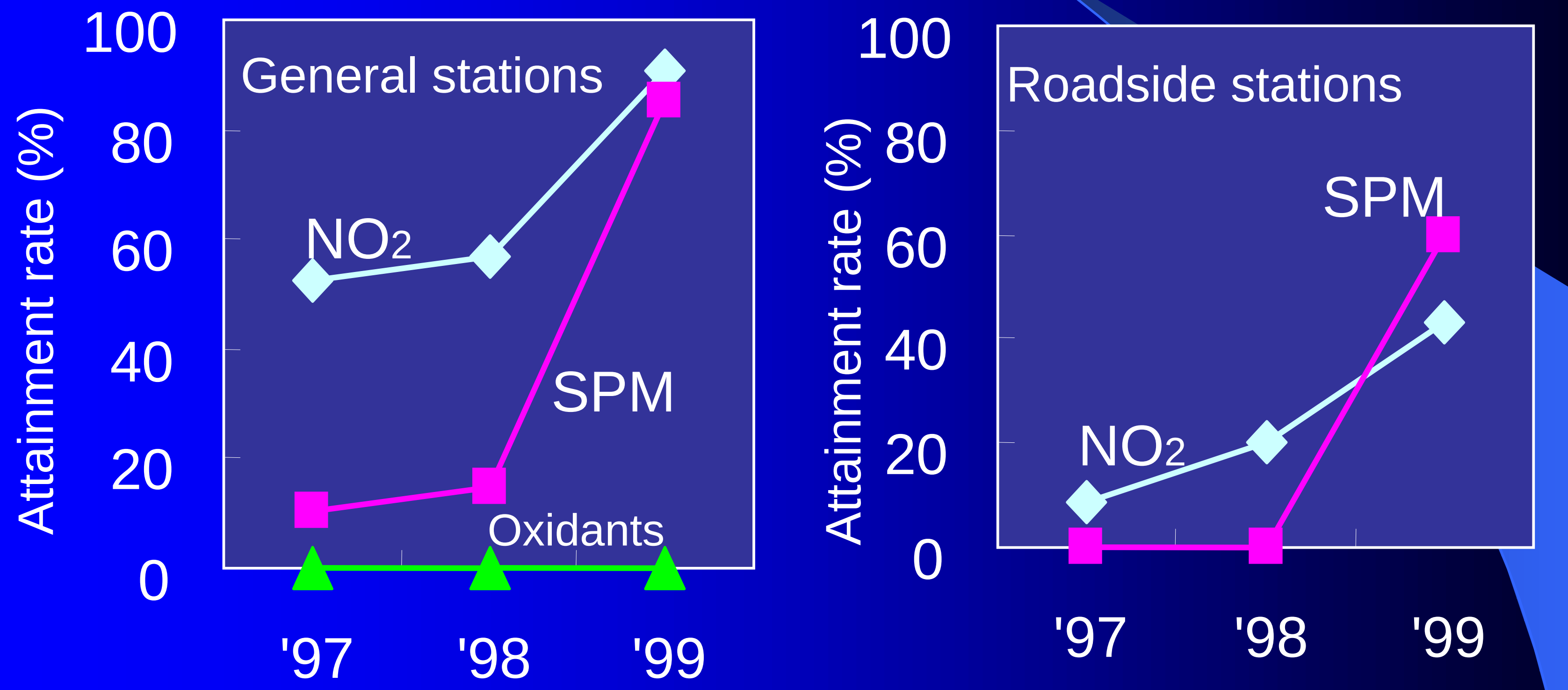
Based on the estimated total emissions from automobiles and other sources,

(1) to analyze the emission reduction effect upon the atmospheric environment by atmospheric model simulation and

(2) to provide information for the establishment of various policies intended for atmospheric improvement.

Current status and issues related to atmospheric environment

-Environmental standards attainment rate in Tokyo Metropolitan area-

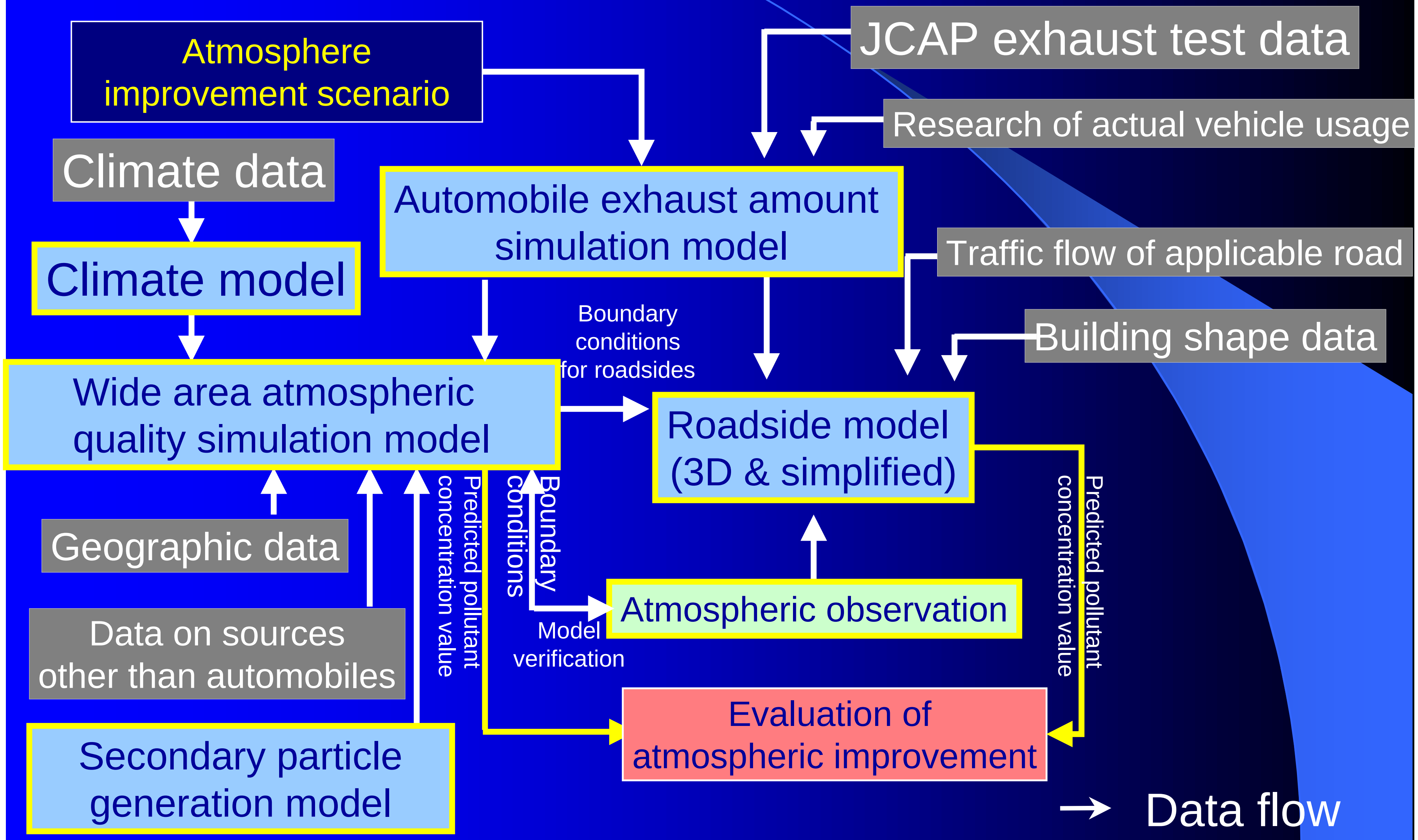


Though the atmospheric quality of the Tokyo Metropolitan area has improved, further improvement is required especially in roadside areas.

source: Tokyo Metropolitan survey data

Outline of Air Modeling WG Study

Overall Structure of Air Simulation Model



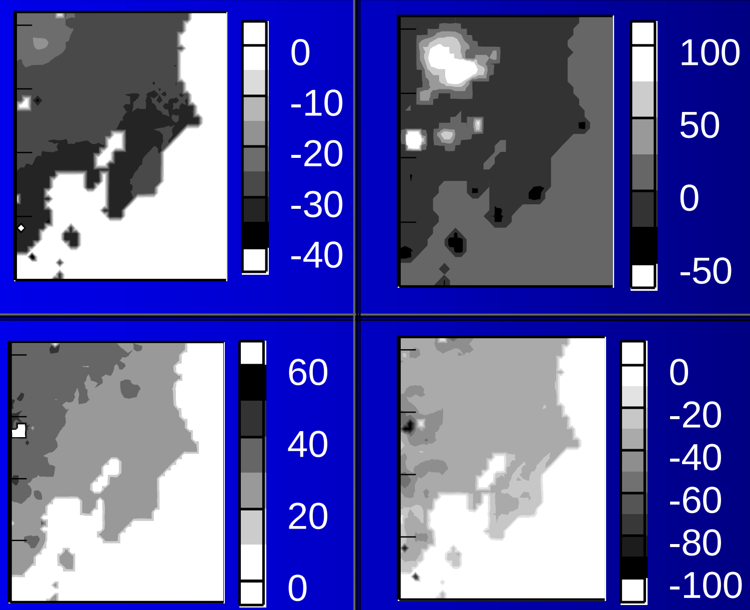
Development of Automobile Emission Amount Simulation Model

- Features of JCAP Estimation Model
  - Reflects the following factors which have not been considered up to now
    - >Exhaust level at engine start
    - >Evaporative emission
    - >Emission level correction (temperature, humidity, catalyst deterioration)
  - Reflects compatibility as an input to the atmospheric quality simulation model
    - >Simulates emission level at every calculation matrix (approx. 5.5 km square)
    - >Simulates emission level every hour
- Development status
  - Basic software for the model has been developed
  - Various correction coefficients and other parameters are being formulated based on the JCAP testing

Example of Emission Level Simulation

Applicable emission sources: tailpipe (hot, at start), evaporative gas(running loss)
The data below reflect the temperature correction, humidity correction, and soak time correction.

	Tailpipe (NOx)	Running Loss (THC)
Summer		
Winter		



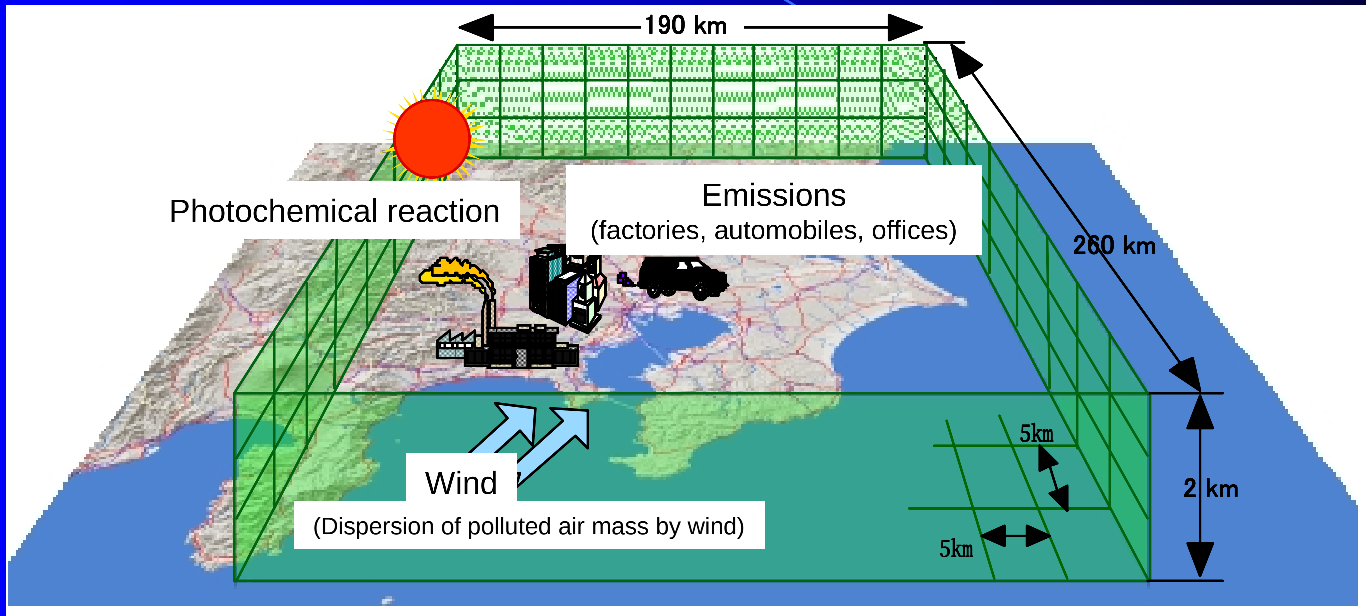
Increase/decrease from base emission amount (%)

Increase/decrease from base emission amount (%)

Time: 2 :00 PM

The above data employ the existing correction coefficients (TRIAS, U.S. EMFAC).
In future, the results of the correction coefficient testing by the JCAP gasoline WG (e.g. temperature correction, soak time correction) will be reflected.

Development Status of 3D Atmospheric Quality Simulation Model



- Calculate and simulate the pollutant emission/dispersion as well as physical/chemical phenomena such as generation and deposition by chemical reaction
- A model is being developed which can simulate an atmospheric quality including secondary particles for the Kanto region
- The currently achieved level of accuracy ensures estimation of ozone, NO2, and inorganic secondary particles

SPM (incl. secondary particles) Concentration Simulation Model

Suspended particle materials (SPM)
- Primary particles
- Secondary particles
  - Inorganic secondary particles
  - Organic secondary particles (under development. Not incorporated yet)

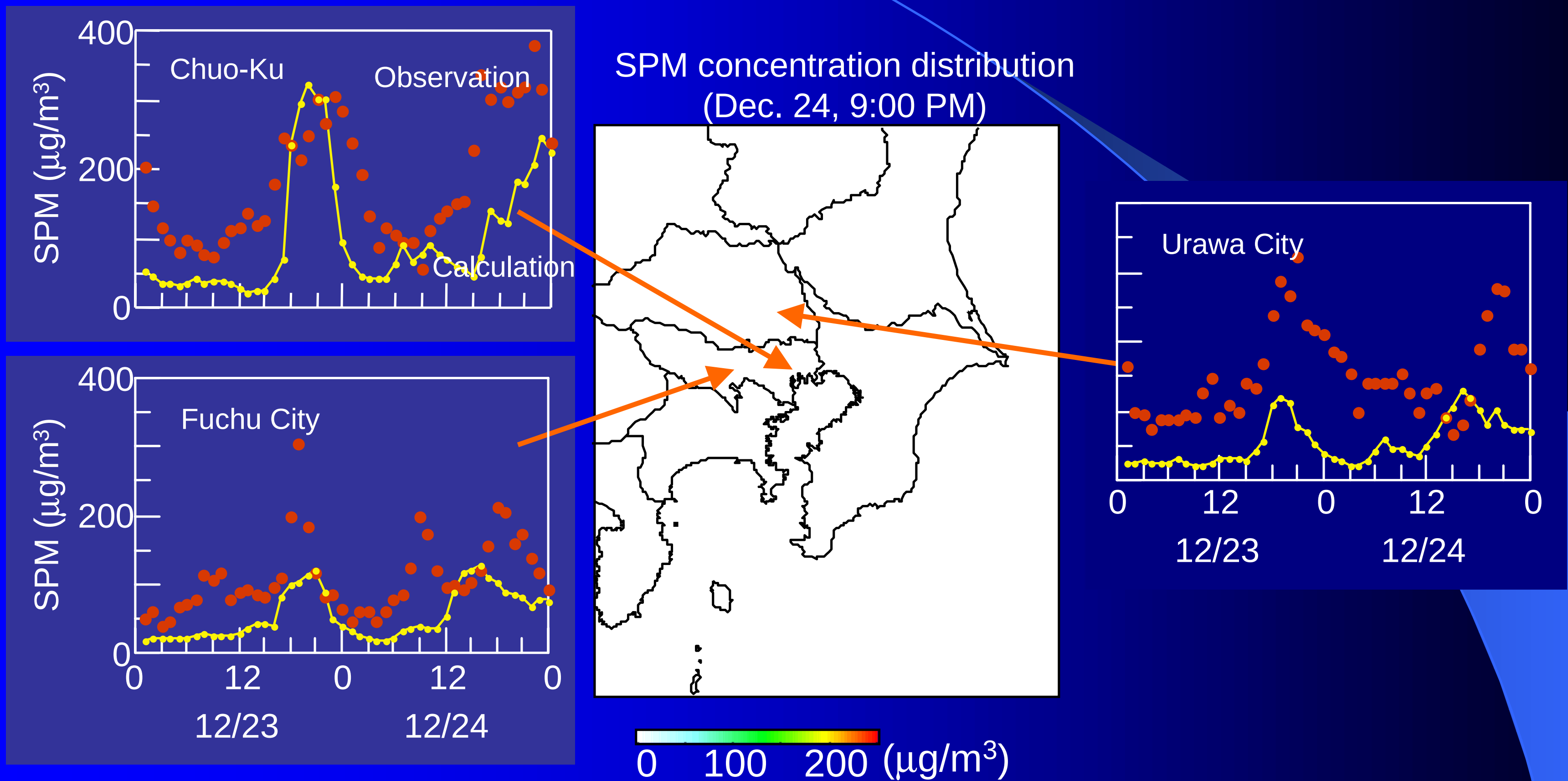
Inorganic secondary particle model (air/solid equilibrium model)

$$A_{(gas)} + B_{(gas)} \rightleftarrows C_{(aerosol)}$$

$$\left(\begin{array}{l} NH_3(g)+HNO_3(g) \rightleftarrows NH_4NO_3(s) \\ NH_3(g)+H_2SO_4(g, l) \rightleftarrows (NH_4)_2SO_4(s) \\ NH_3(g)+HCl(g) \rightleftarrows NH_4Cl(s) \end{array} \right)$$

Chemical equilibrium constant $K = \alpha \exp\{\beta(T)\}$

Example of SPM (incl. secondary particles) Concentration Simulation Model

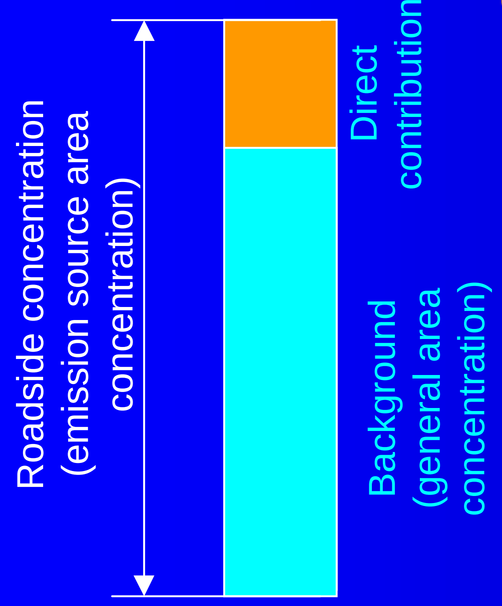


The calculation almost matches the actual observation in the center of the city.
The concentration in suburbs, however, is likely to be underestimated.

Method of Roadside Atmospheric Quality Simulation - Simple Method

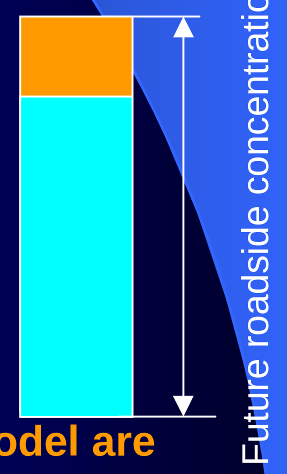
Roadside concentration (emission source area concentration) = Background concentration (general area concentration) + Direct contribution from running vehicles

Current roadside concentration



Change in direct emission contribution is proportional to vehicle emission reduction rate

Future roadside concentration



For reduction in background concentration, the results of the wide area atmospheric model are used.

Atmospheric Observation

- Purpose of atmospheric observation
  - Verification of atmospheric quality simulation model
  - Acquisition of atmospheric model input data such as initial conditions and boundary conditions

- Three observations conducted so far. Analysis underway

  - Summer / 1999 (wide area observation in Kanto plane)
  - Early winter / 1999 (wide area observation in Kanto plane)
  - Summer / 2000 (wide area observation in Kanto plane)
  - Early winter / 2000 (planning a roadside observation)

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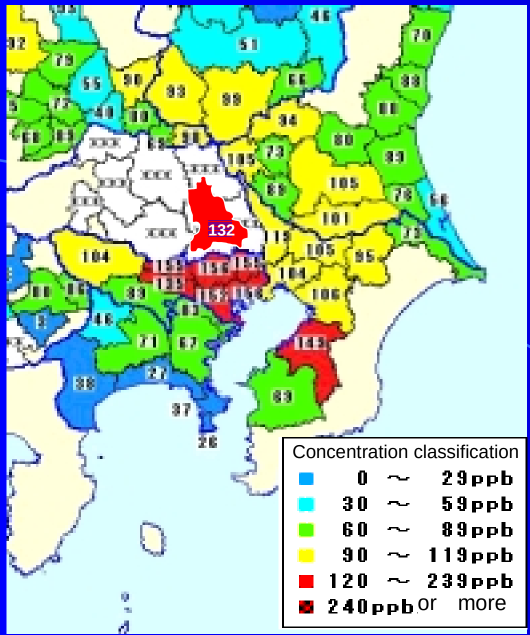
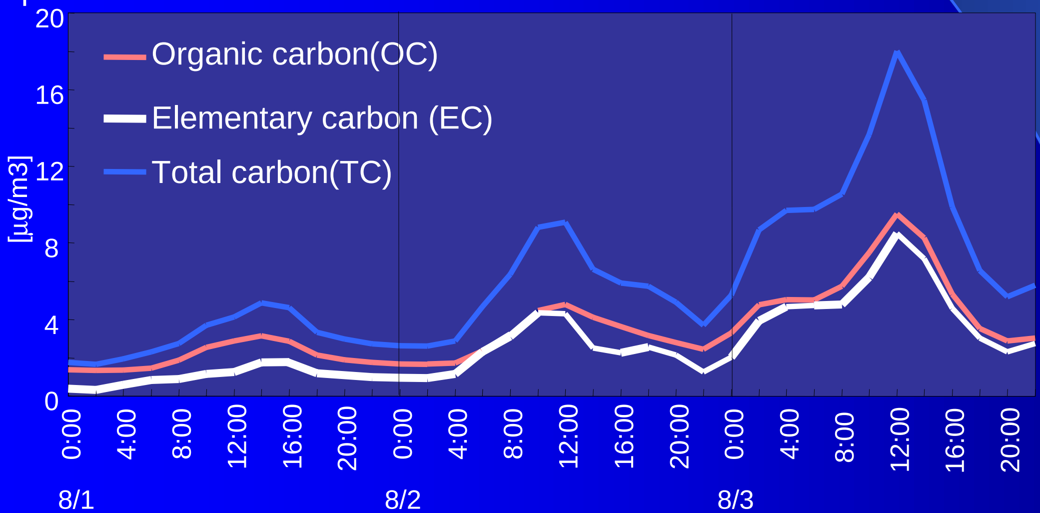
Example of Atmospheric Observation in Summer / 2000



Ground level observation: photochemical oxidant concentration

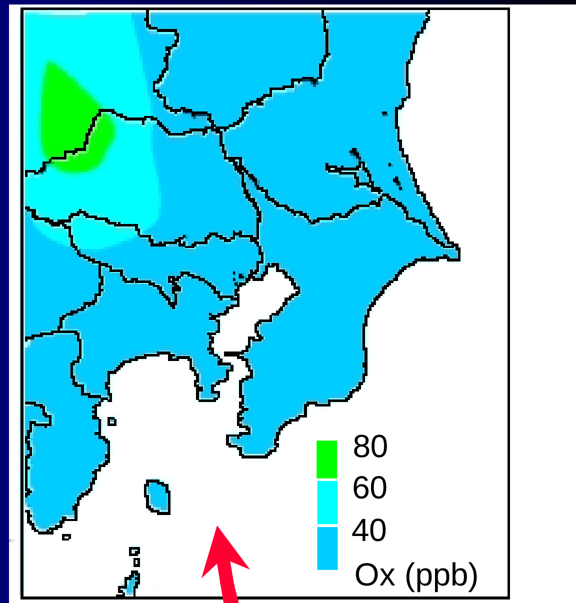
- Photochemical smog warning issued
- High concentration of oxidants and particles measured

Aerial observation: Midair with poor visibility



Ground level observation(Carbon concentration in particles)

Summer /2000 atmospheric observation



- Strong south wind blowing at 2000 m level even in upcountries and creating very pure atmospheric environment
- Very little generation of secondary particles

Evaluation of Atmospheric Quality Improvement Effects by Diesel PM Countermeasures

The main analysis target is;

How much effect can the reduction of diesel emissions have on the concentration of suspected particle materials (SPM)?

Evaluation Contents

- Evaluation of emission reduction effect
  – Estimated by the JCAP automobile exhaust level estimation model
- Evaluation of wide area atmospheric quality improvement effect
  - SPM (incl. inorganic secondary particles) concentration predicted on the basis of the 3D atmospheric quality simulation model
- Evaluation of roadside atmospheric quality improvement effect
  - SPM concentration in roadsides areas predicted by the simplified method

Cases of Diesel Countermeasures Evaluated

	Case	Before 1989	Short term	Long term	New short term	New long term
1	1994	Reference				
2	2000		Base (estimation)			
3	2005 (Spontaneous replacement)		Spontaneous replacement with latest reg. compliant vehicles			
4	**Combination of Measure - A**	To long term reg. compliant veh.	DPF retrofit (70%)	Spontaneous replacement	New long term level	
5	**Combination of Measures - B**	To long term reg. compliant veh.	Oxidation catalyst (50%)	Spontaneous replacement	New long term level	
6	DPF retrofit - A	DPF retrofit (70%)			New long term level	
7	DPF retrofit - B	DPF retrofit (85%)				
8	**Perfect Replacement with new long term reg. Compliant vehicle**					All meet new long term reg.

* Evaluation year for above 3 to 8 is 2005. ( ) indicates PM removal rate.

Assumptions of Automobile Emission Estimation

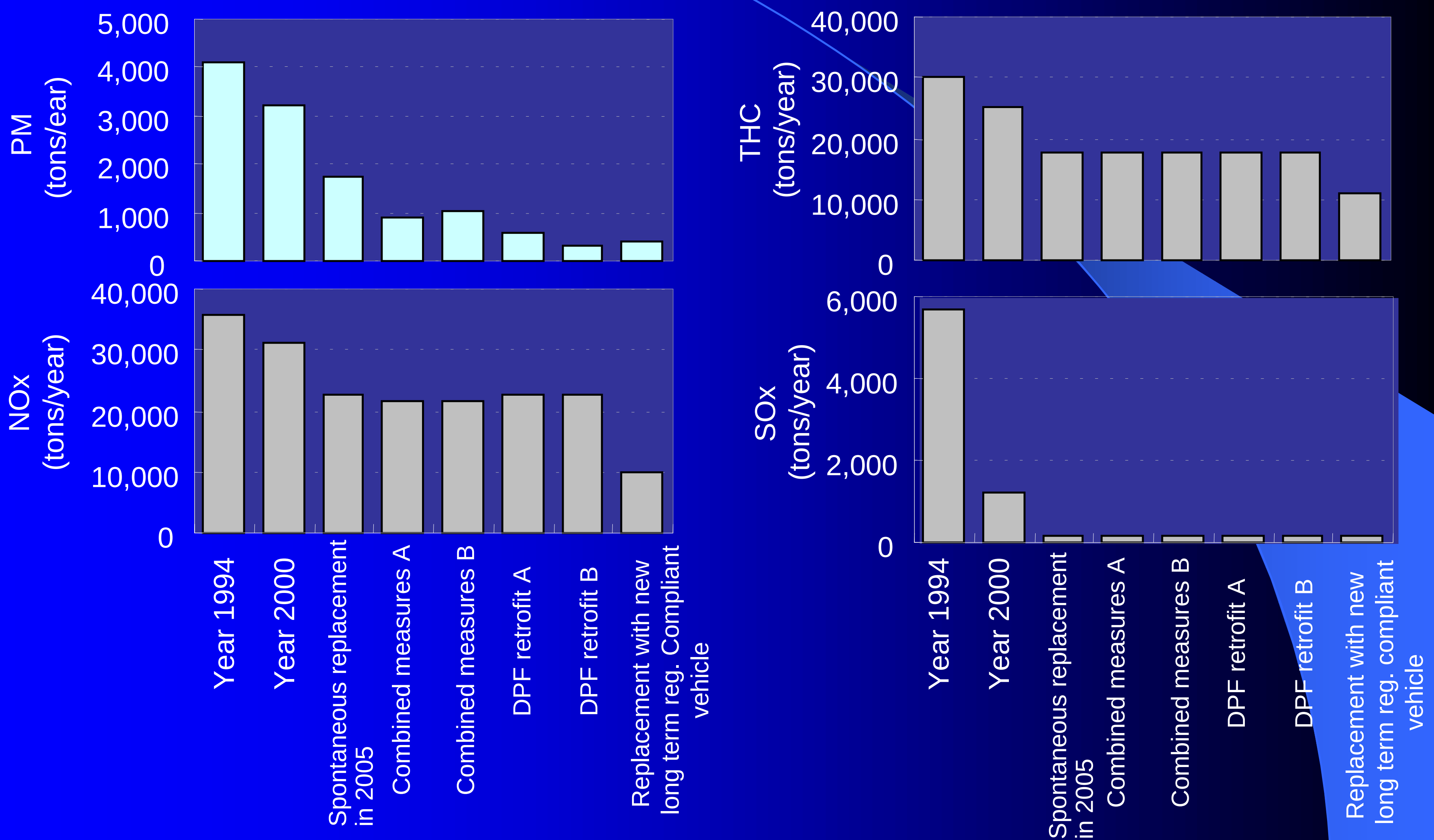
Emission amount = Emission coefficient by vehicle model and MY x Mileage by vehicle model and MY

- Emission coefficient (g/km/vehicle)
  - 1989 regulations compliant vehicles (part of short term regulations compliant vehicles) : Basic unit set by Environment Agency
  - Vehicles after 1989 regulations: Coefficient for 1989 regulations compliant vehicles x reduction rate for the reg. criterion
  - Coefficient for dust swirl and tire dust: SPM Pollution Prediction Manual (Environment Agency)
- Mileage (unit x km)

  Predicted for year 2000 and year 2005 from the JCAP future traffic prediction research data (1998, 2020) and the traffic census data (1994, 1997)
- Sulfur spec. of diesel fuel
  - 1994 0.2 %
  - 2000 0.05 %
  - 2005 50 ppm (assumption)

Tailpipe Emissions Reduction Effect

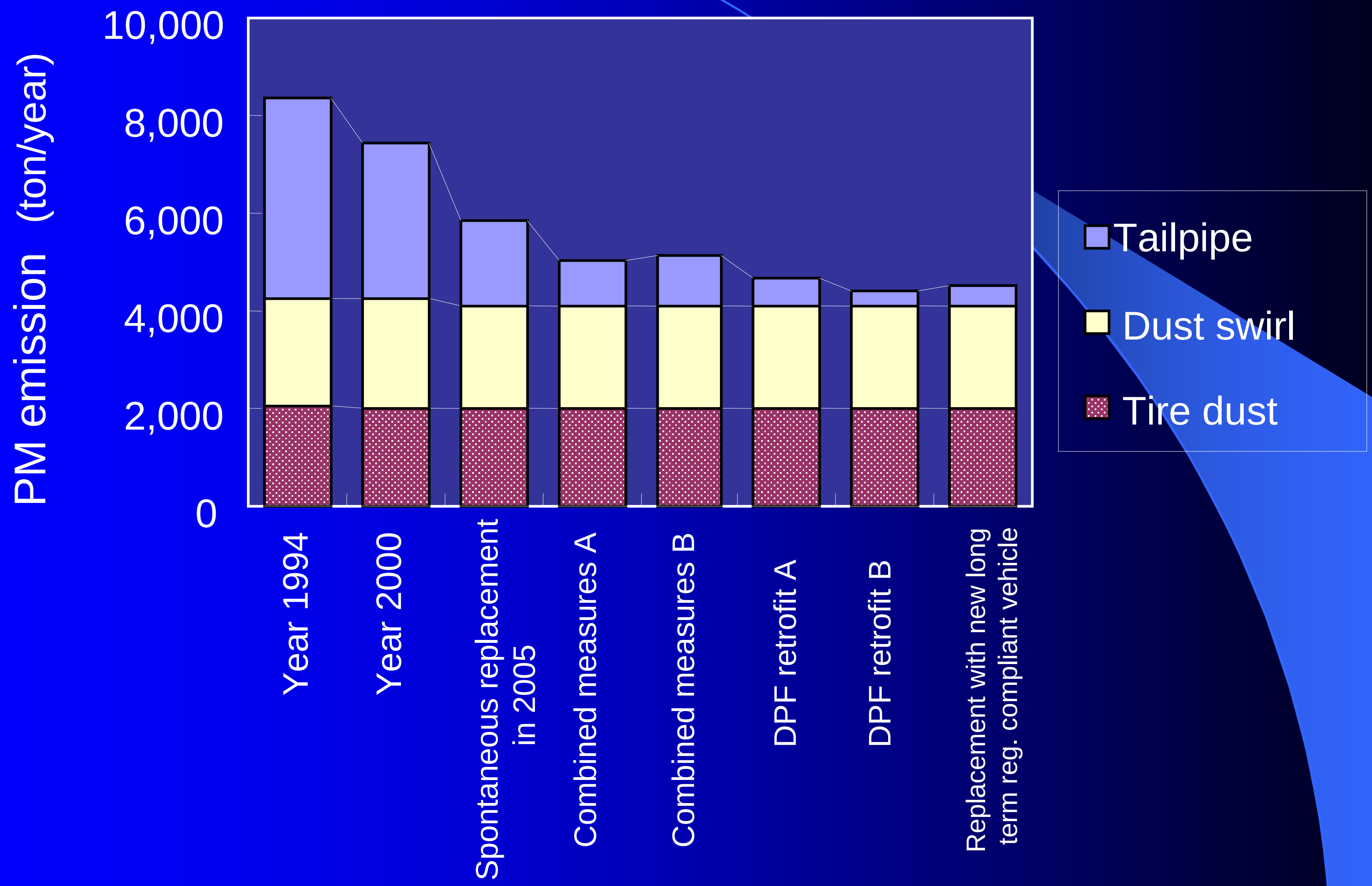
- All Tokyo Metropolitan Areas -



The changes in emissions include contribution by spontaneous replacement of gasoline vehicles

Total PM Emission Amount from Automobiles

- All Tokyo Metropolitan Area -



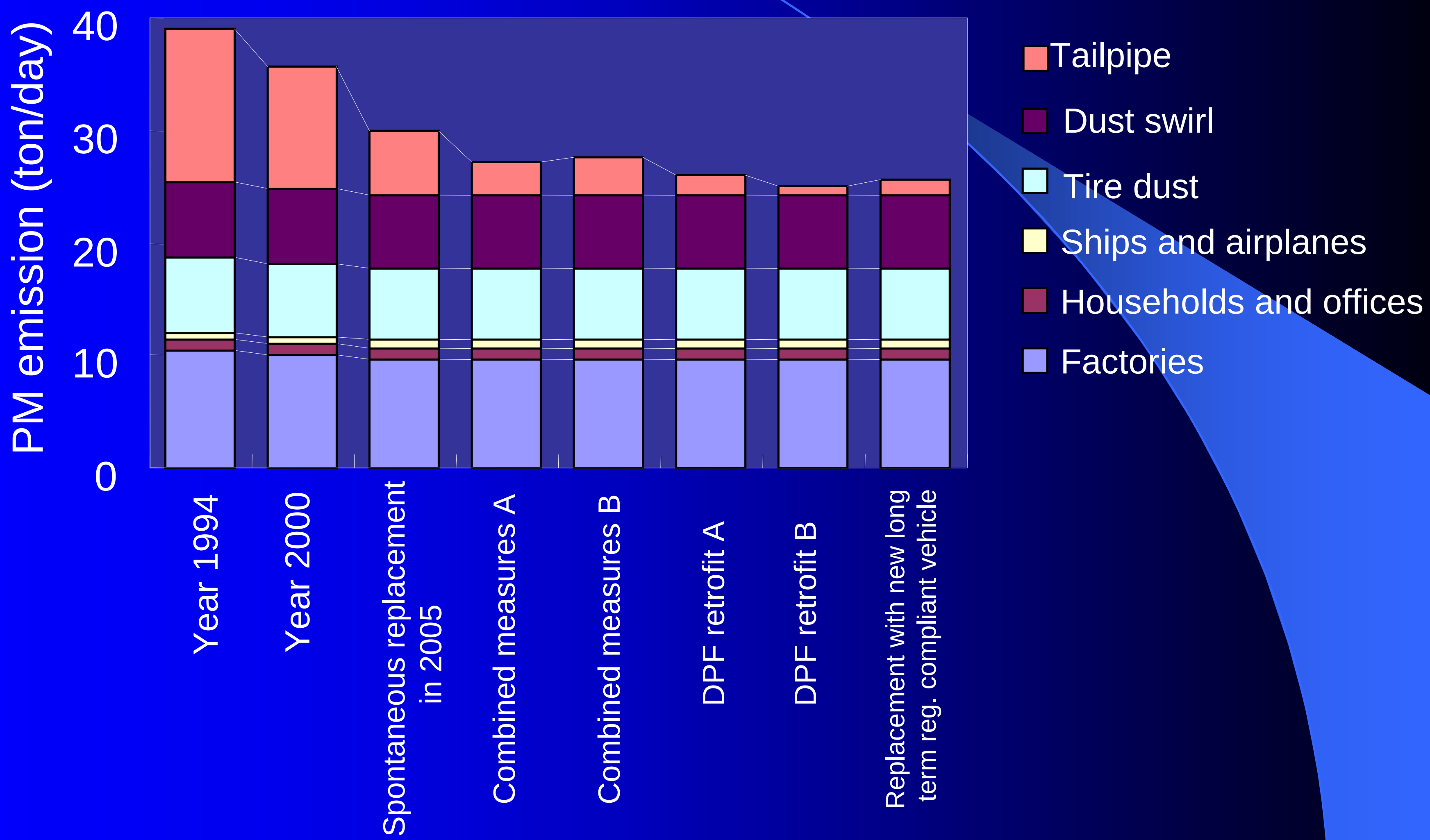
Emission coefficient for dust swirl and tire dust: Data from SPM Pollution Prediction Manual (Environment Agency) used.

Summary (1) - Emission Estimation Result

Emissions from automobiles in Tokyo in 2005

- Tailpipe PM emission
  - In case of spontaneous replacement: Will decrease to 54% of 2000 level.
  - Various measures implemented: Further decreases to half or even one-third or less of 2000 level.
  - The effect by tire dust and dust swirl is greater than that of tailpipe emission.
  - The improvement case in which all diesel vehicles are retrofitted with DPF will give the largest reduction effect.
  - In practical terms, no significant differences seem to be present across the effects of various countermeasures.
- HC and NOx emission
  - Except for replacing all vehicles with new long term reg. compliant vehicles, no countermeasures can give meaningful additional effect compared to spontaneous replacement.
- SOx emission
  - Decreases in proportion to sulfur level in light oil.

PM Emission from Various Sources
- Entire Tokyo Area -



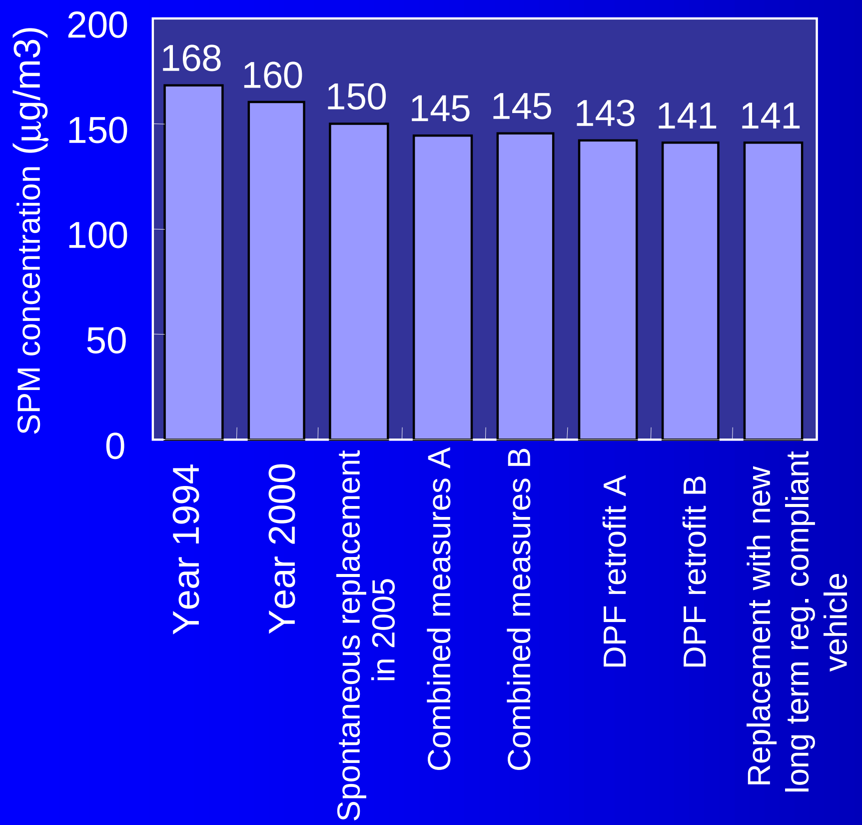
Simulation of Wide Area Atmospheric Quality (SPM) - Calculation Condition

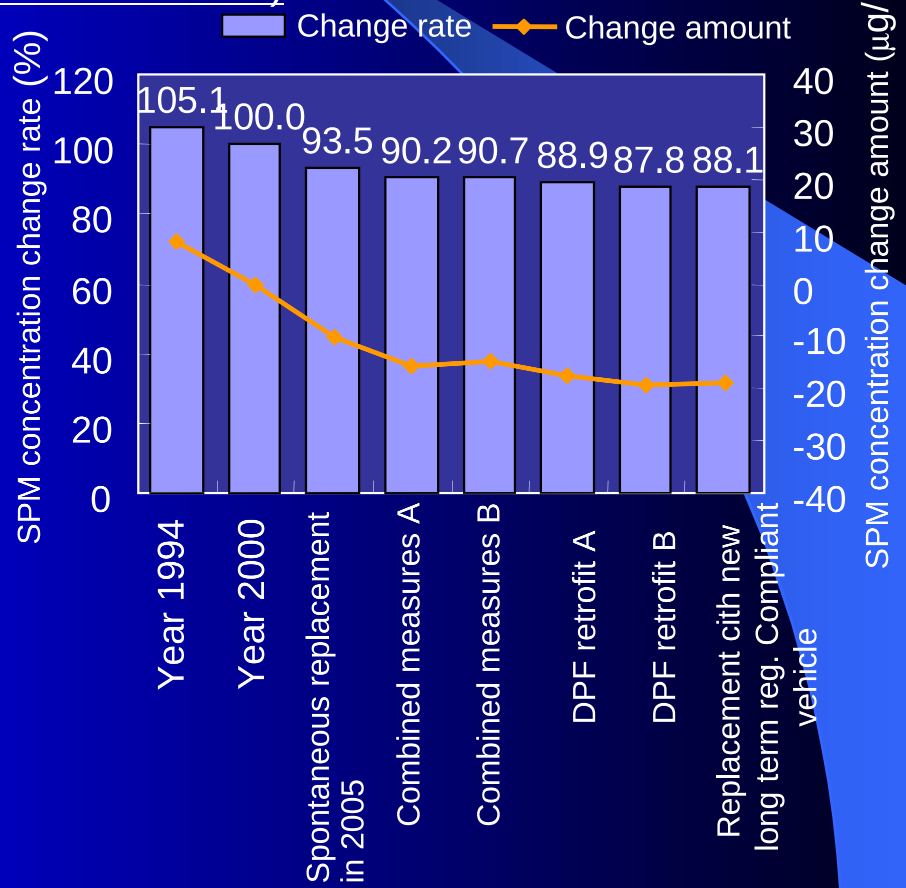
- Simulation of SPM concentration including inorganic secondary particles carried out
- Atmospheric simulation model
  - CIT Airshed Model
  - Photochemical reaction model: SAPRC90
  - Inorganic secondary particle model: SCAPE2 (Air/solid equilibrium model)
- Calculation conditions
  - Applicable area: Kanto plane
  - Climate conditions: Those in the period from 12/23/1994 to 12/25/1994 (climate conditions with high SPM concentration)
  - Emission data:
    - Except automobiles: 2000 and 2005 data interpolated from 1994 data and 2010 estimation.
    - Automobile emission: Calculated by means of JCAP estimation model

SPM Concentration Reduction from Diesel Countermeasures

Average SPM concentration for 24 hours in all 23 wards of Tokyo

SPM concentration = Observation concentration in 1994 - Change amount (result of model calculation)





Date: 12/24/1994 (high SPM concentration detected)

Summary (2) - Effect on Wide Area Atmospheric Quality

Effect on wide area atmospheric quality under high SPM concentration conditions in 2005

- SPM concentration in wide area atmosphere

  (average among 23 wards of Tokyo)

  -Spontaneous replacement: 7% reduction from 2000 level

  -Various measures implemented: 13% max. reduction from 2000 level

- Effects of various SPM reduction measures

  -Though tailpipe SPM is reduced to one-third or less, the SPM concentration under high concentration conditions is reduced by only 10% from 2000 level, a small effect compared to the emission reduction.

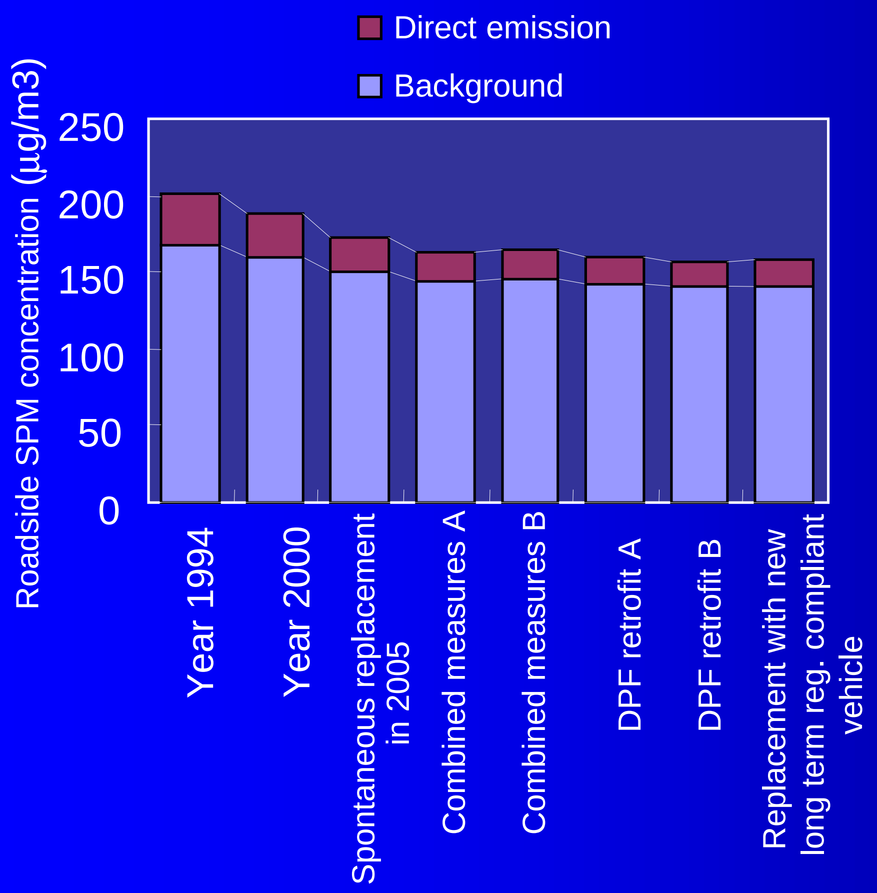
- Next step

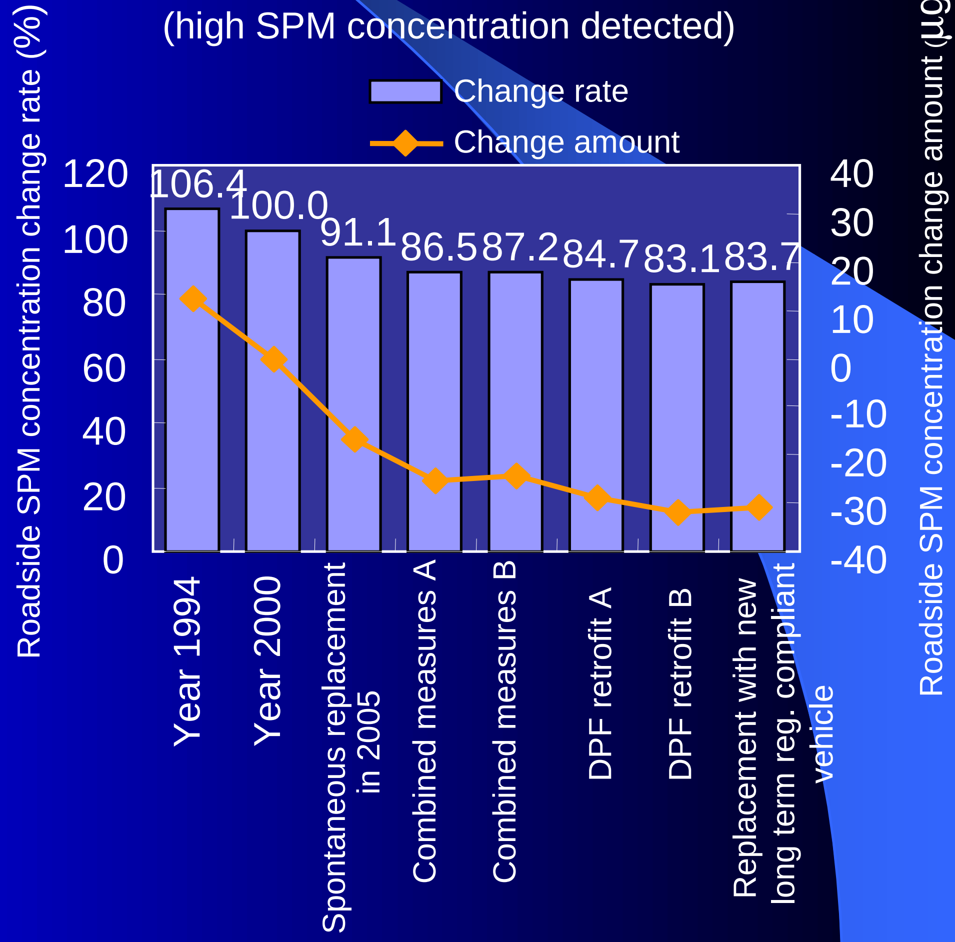
  -Although the tailpipe emissions are reduced, the contribution by other fixed pollution sources increases. Comprehensive measures will be an important key.

Improvement of Roadside SPM Concentration by Diesel Countermeasures

—Average among 23 wards of Tokyo—

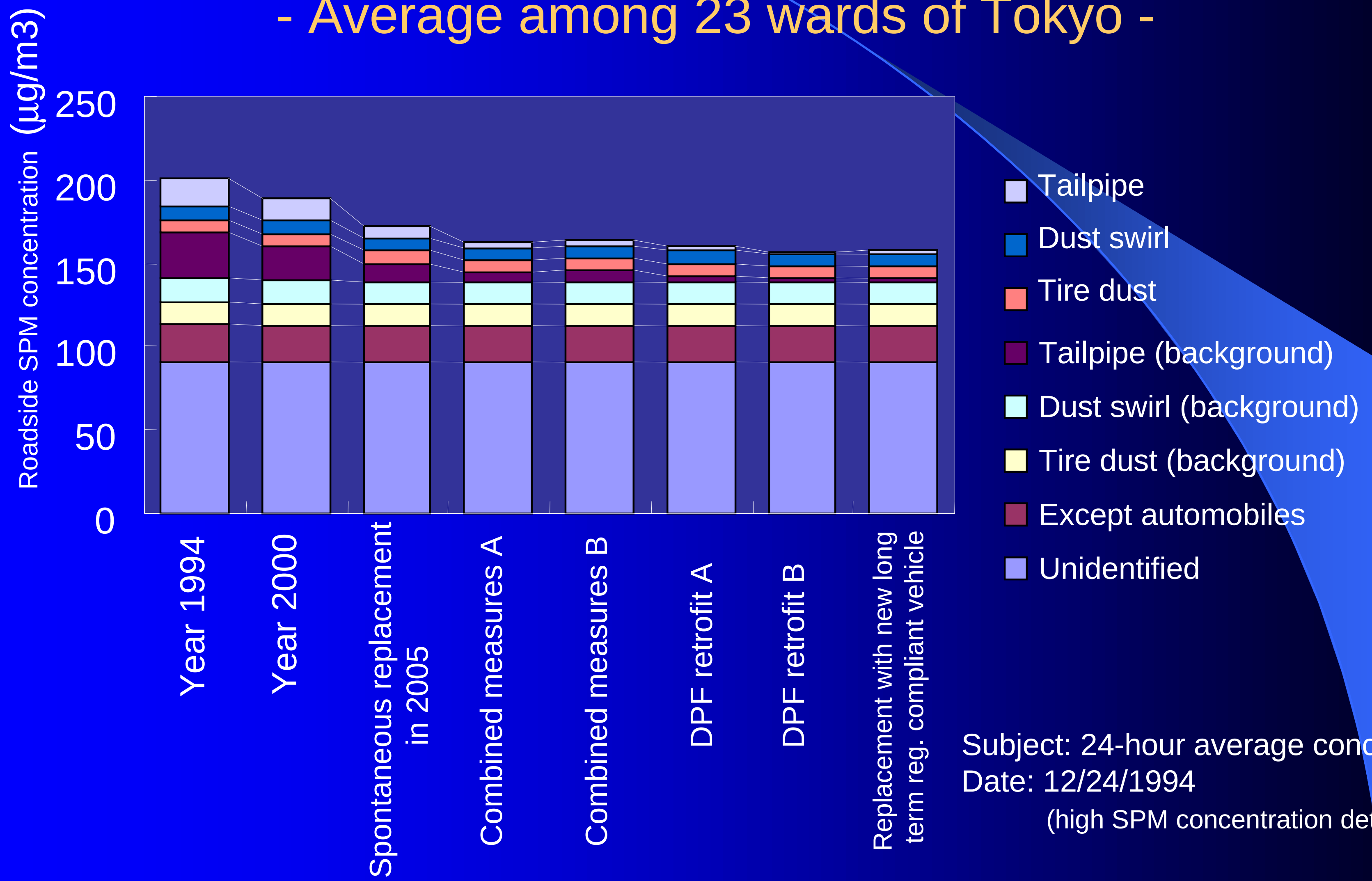
Evaluation subject: 24-hour average concentration Date: 12/24/1994
(high SPM concentration detected)





Contribution of Various Sources to Roadside SPM Concentration

- Average among 23 wards of Tokyo -

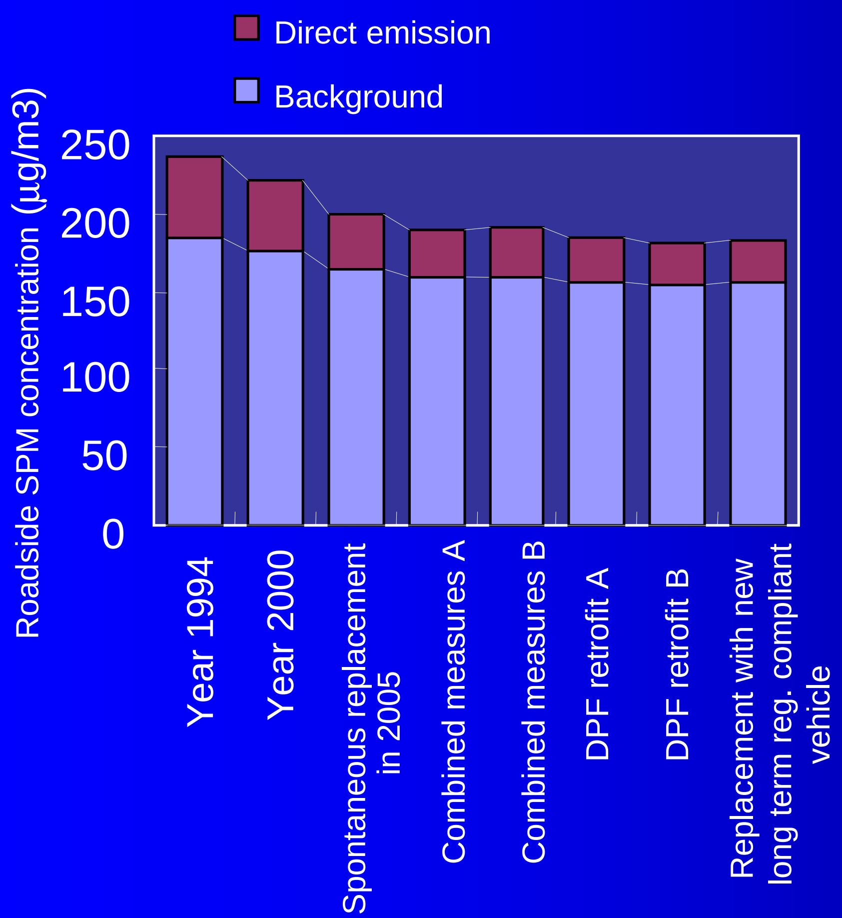


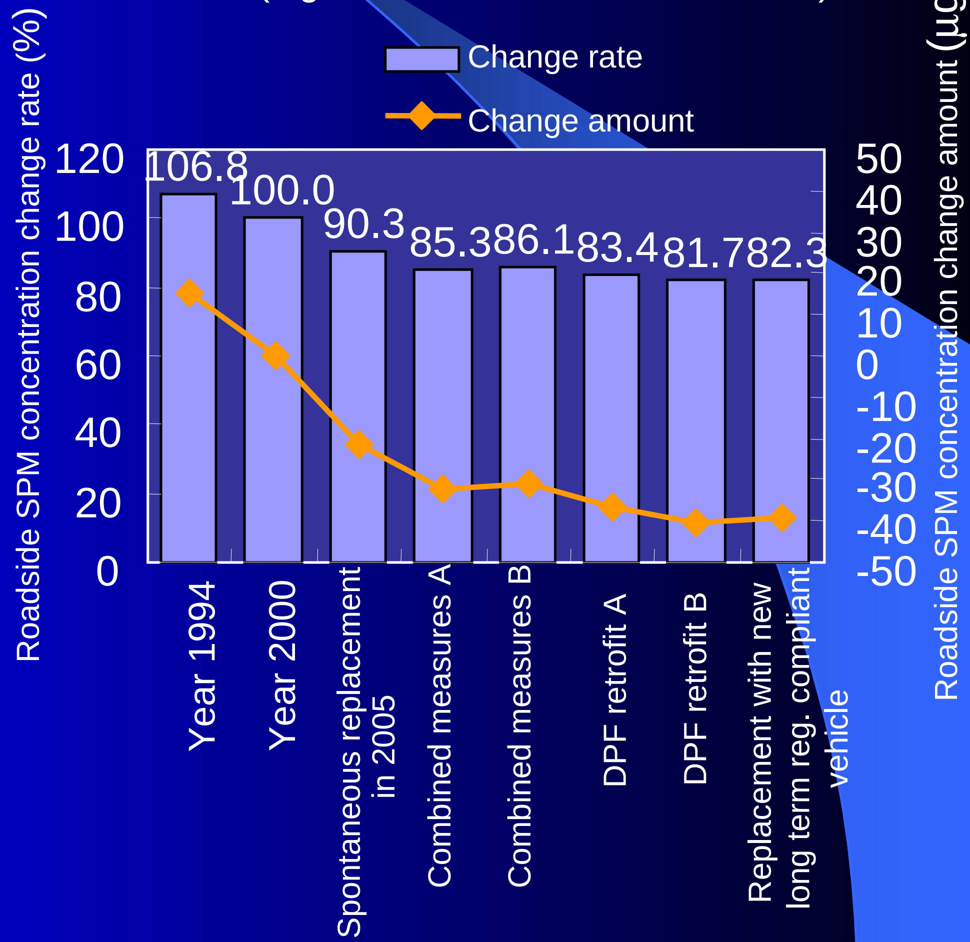
Subject: 24-hour average concentration
Date: 12/24/1994
(high SPM concentration detected)

Improvement of Roadside SPM Concentration by Diesel Measures

- Matsubara Bridge -

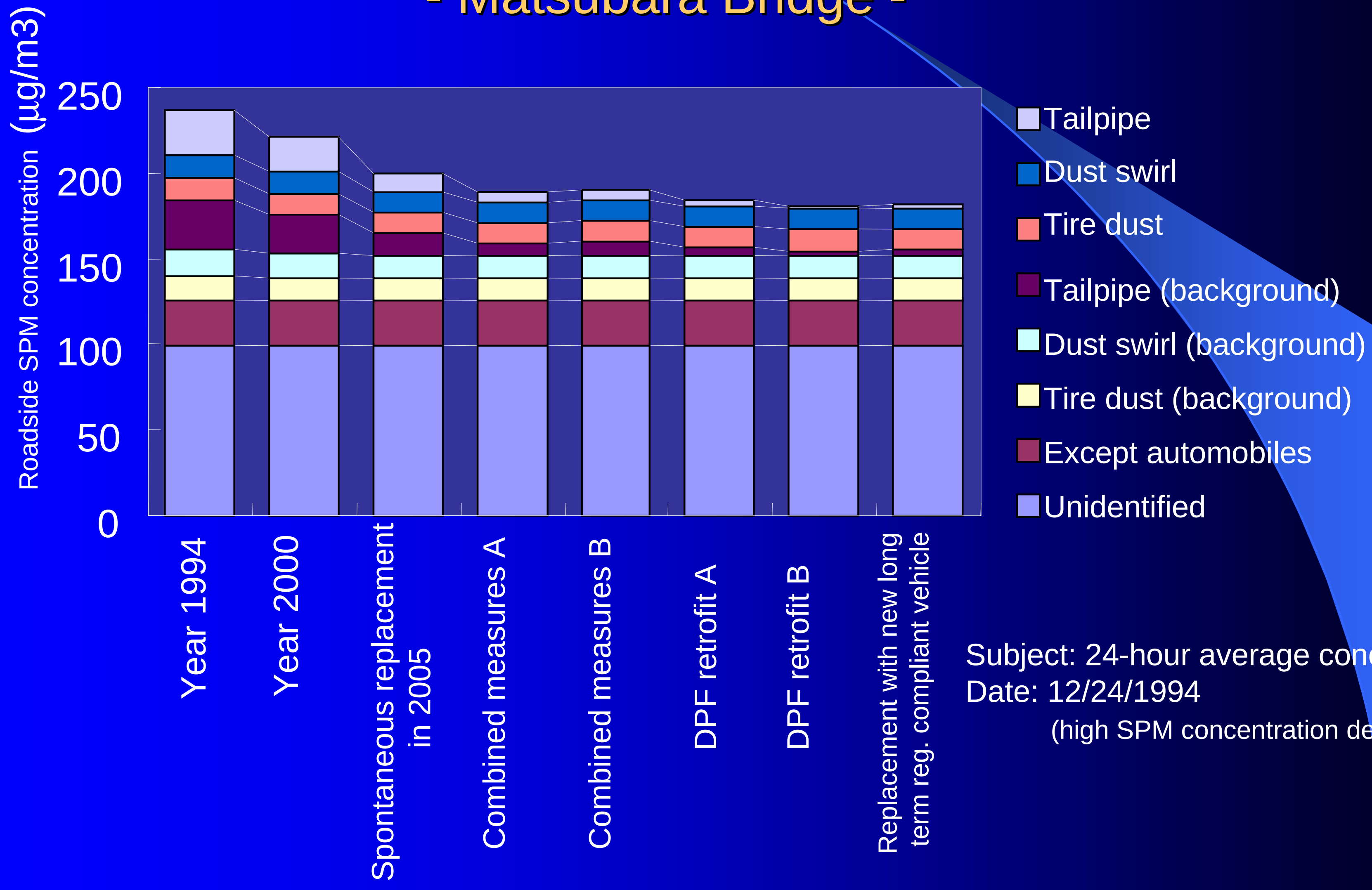
Evaluation subject: 24-hour average concentration Date: 12/24/1994 (high SPM concentration detected)





Contribution of Various Sources to Roadside SPM Concentration

- Matsubara Bridge -



Subject: 24-hour average concentration
Date: 12/24/1994
(high SPM concentration detected)

Summary (3) - Effects on Road Side Atmospheric Quality -

Under high SPM concentration condition in 2005:

- Roadside SPM concentration (average among 23 wards of Tokyo)
  - Spontaneous replacement: 10% lower than 2000 level
  - Various measures implemented: Max. 20% lower than 2000 level
- Roadside SPM concentration (Matsubara Bridge)
  - The Matsubara Bridge area was also evaluated where the contribution of vehicle emissions is considered high
  - The improvement rate of SPM concentration is almost equivalent to that of Tokyo 23 wards
- Effect of background concentration in roadsides
  - 10% to 20% of roadside concentration comes directly from automobile emissions
  - Even in roadsides, the effect of background concentration is significantly large
- Next step
  - Organic secondary particles, dust swirl, and tire dust are not identified sufficiently. To be studied as an important issue.

General Summary

- In all simulations as of 2005, according to emission simulaton, wide area atmospheric quality simulation and roadside simulation, spontaneous replacement accounts for a large part of the reduction rate. Implementation of various measures will lead to further reduction.

2. All atmospheric quality improvement measures evaluated here provide almost equivalent effects. This indicates that the selection of countermeasure should be based on ease of implementation and costs.

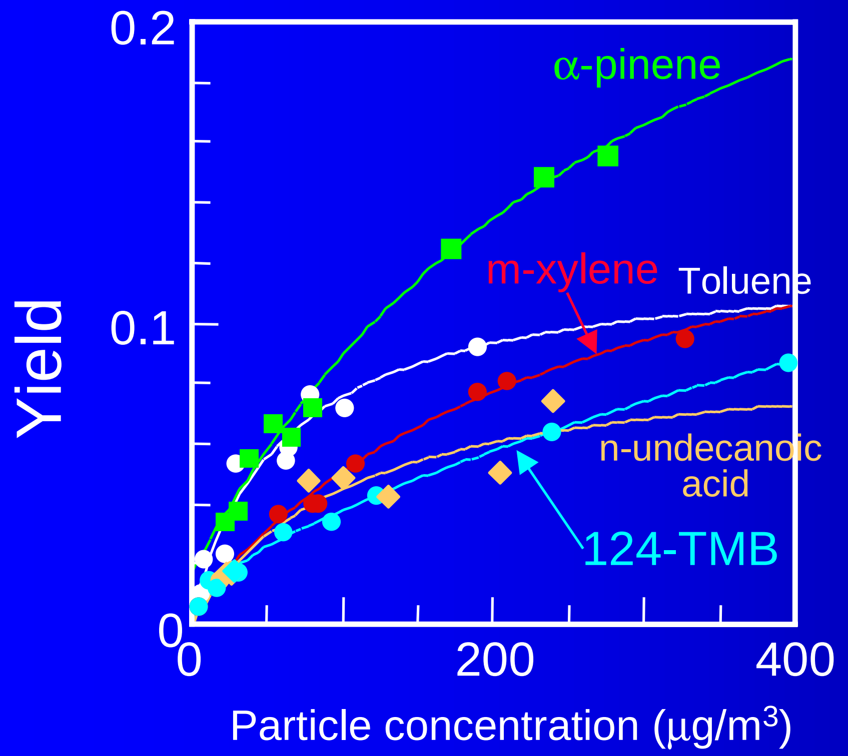
3. In the long run, remarkable results are expected. For example, significant reduction of tailpipe contribution, when all vehicles meet the new long-term regulations.

Next Step and Prospects

- Development and improvement of organic/inorganic secondary particle generation model and verification by atmospheric observation and other means (being developed)
- Development and verification of 3D roadside model (being developed)
- Collection and organization of SPM source data (tire dust, dust swirl, sources except automobiles, unidentified sources,etc.)

Development of Organic Secondary Particle Model

Organic secondary particle yield of major hydrocarbons



Test conditions：303 K, 60 % RH

Base model

$$\text{Yield} = M_o \sum \frac{\alpha_i K_i}{(1 + K_i M_o)}$$

M_o ; Particle concentration

α_i ; Yield of semivolatile reaction product i

K_i ; Gas/particle distribution constant of i

	α_1	K_1	α_2	K_2
Toluene	0.112	0.0153	0.004	
m-xylene	0.168	0.0038	0.004	1.53
124-TMB*	0.262	0.0009	0.019	0.061
α-pinene	0.316	0.0030	0.017	
n-undecanoic acid	0.092	0.0095		

*Trimethylbenzene

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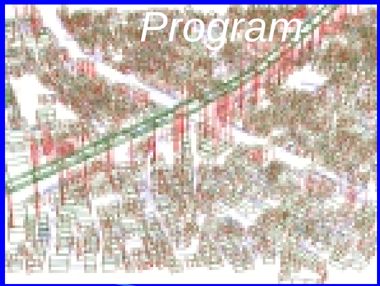
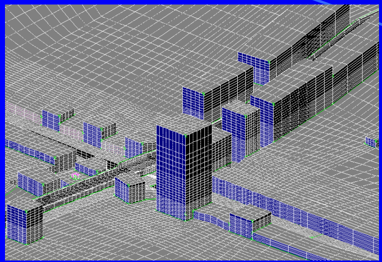
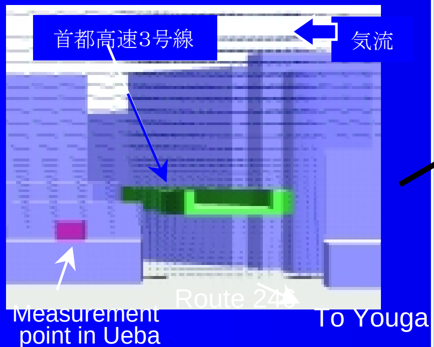
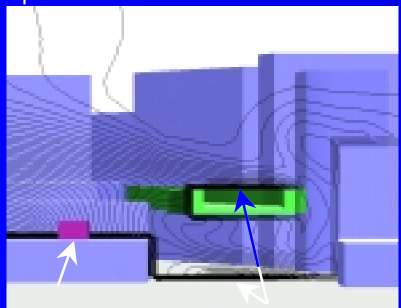
Development of 3D Roadside Model









Measurement point in Ueba

Gases exhausted in the road diffuse in the street canyon

Shape data of buildings along the road

Calculation matrix

Air stream model

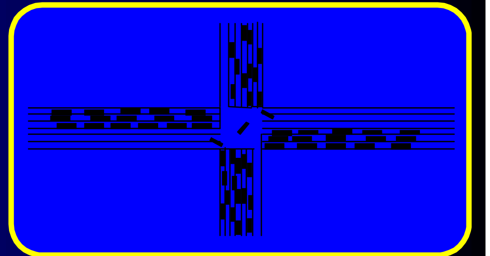
Air stream field at roadside

Advective diffusion model

Diffusion concentration field along automobile exhaust at roadside

Traffic parameters along roadside
(road layout, signal configuration, traffic amount, etc.)

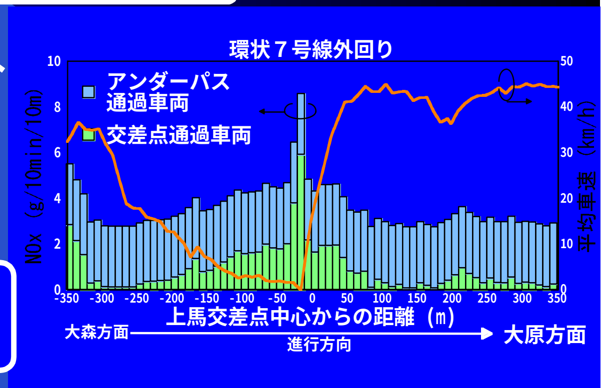
Micro scale traffic flow model



Traffic flow at roadside
(All vehicles' positions/speed/acceleration at every second)

Transient emission coefficient

Exhaust emission distribution at roadside



Background concentration by wide area

Concentration field in roadside

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