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A modeling study of the impact of natural and urban forest on ambient ozone

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Abstract−Impact estimation of biogenic VOCs (Volatile Organic Compounds) to control ambient ozone is needed. For this, BVOCs emission is calculated by using BEIS, and the impact of ozone is estimated with UAM in the research area, Daegu metropolitan city. It is estimated that 59 ppb and 50 ppb of ozone concentration is caused by BVOCs emissions and anthropogenic emissions, respectively. As for tree type, deciduous trees have greater influence than conifers on the daily maximum 1-hr ozone concentration though the former's distribution area is smaller than the latter's. In addition, variation of ozone concentration by BVOCs emission is more sensitive in city areas compared to rural areas. If we change the landscape from woody plants (urban trees) to lower ozone-forming potential (OFP) species, it should lead to a reduction in grids that exceed the national ambient ozone standard.

Key words: Biogenic Volatile Organic Compound, Isoprene, Monoterpene, BEIS, Ozone

INTRODUCTION

In view of environmental resources, trees have affirmative functions of territorial integrity, pleasant environment creation, beautification of cities, etc. The trees of cities, especially, clear air pollutants like CO_2 during photosynthesis. But trees have negative aspects of transpiring volatile organic compounds (VOC) during their growth.

Along with NOx, VOCs are an important precursor of tropospheric photochemical ozone. It is known that VOCs are transpired largely from anthropogenic sources through the use of paint, and organic products, etc., but it is also from natural sources, and this can exceed the emission amount from anthropogenic pollution sources in some areas.

Tropospheric photochemical ozone needs to be controlled as a main factor of air pollution, and to do this, it is essential to control VOCs, and to figure out the effect of biogenic VOCs for effective management.

The scientific research about the emission of biogenic VOCs and emission from trees started in Russia in 1928, and measurement data of the BVOCs emission rate during the 1950's [1]. The research about the emission amount of BVOCs started in North America during the 1950's [2], after the hypothesis that the emission rate of BVOCs can greatly affect atmospheric chemistry reactions [3], studies about types of BVOCs [4-7], emission rates [8-13], and behavior in air [14,15] have proceeded.

BVOCs are mostly reactive olefin compounds. Isoprene is mainly emitted from deciduous trees, monoterpenes, like α-pinene and β-pinene from conifers. The contribution degree of BVOCs to ozone creation is relatively higher than anthropogenic VOCs [16], since BVOCs emission from trees, especially the reactivity of isoprene, is higher than the mean reactivity of VOCs emissions from anthropogenic emission sources [17]. In recent years, BVOCs have been found to play an important role in making ozone in cities of the United States and local areas. Therefore in 1991, the U.S. EPA demanded that natural emissions should be included in photochemical modeling.

In this study, we estimated the BVOCs emissions from natural forests and urban forests, using the BEIS2 (Biogenic Emission Inventory System. ver. 2) of U.S. EPA in the center of Daegu city which is promoting a project of planting one million trees every year. We predicted the effect of BVOCs, emissions from a natural forest to the ozone concentration, applying the photochemical pollution model, UAM (Urban Airshed Model version 6.21). We divided the urban forest into cultured trees and non-cultured trees, and we figured the effect of the urban forest on the ozone concentration. We predicted the effect of the change of types and amount of cultured trees on the ozone concentration.

MODELING DESCRIPTION

1. UAM-IV Model

UAM is a 3D photochemical grid model which was developed to calculate the concentration of reactive and non-reactive air pollutants, and the effect of physical·chemical reactions on the concentration of air pollution compounds. UAM is based on the continuity equation, advection/diffusion equation, and the emission, transportation, diffusion, chemical reaction and emission process of pollution compounds expressed mathematically according to mass balance.

2. BEIS2 Model

BEIS2, which was developed in 1994 [18], is used most often to obtain estimates of natural emissions. BEIS2 divides the land use of the targeted area into forest, city, farm land, etc. and it categorizes according to the characteristics of vegetation and land; then it calculates the emission amount, applying the emission coefficient per vegetation. The emissions from vegetation are very sensitive to weather variables such as solar radiation, temperature, wind, so in consideration of this effect, the final emission is calculated. To calculate the emissions of BVOCs by vegetation, the density of vegetation is necessary, and variables compensated with respect to changes in season and environment, and vegetation type.

BEIS2, divided into forested area and non-forested area like below, calculates the emission of BVOCs, using the equation, proposed

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by Guenther et al. [19] (ASC [20]).

The Eq. (1) for the emission of forested areas is the following:

$$ER_i = \sum_{j=1}^{n} [A_j \cdot FF_j \cdot EF_{ij} \cdot F(S,T)] \quad (1)$$

ER_i : Emission rate of each chemical species (i) [μg/hr]
A_j : Area of vegetation for each vegetation type (j) [m^2]
FF_j : Foliar density factor for each vegetation type (j) [g leaf biomass/m^2]
EF_{ij} : Emission factor for each chemical species (i), and vegetation type (j) [μg/g leaf biomass/hr]
F(S, T) : Environmental factor accounting for solar radiation (S), and leaf temperature [T] (unitless)

The Eq. (2) for the emission of non-forested area is the following:

$$ER_i = \sum_{j=1}^{n} [A_j \cdot EF_{ij} \cdot F(S,T)] \quad (2)$$

ER_i : Emission rate of each chemical species (i) [μg/hr]
A_j : Area of each land use type (j) [m^2]
EF_i : Emission flux factor for each chemical species (i), and each land use type (j) [μg/m^2/hr]
$F_{ij}(S, T)$: Environmental factor accounting for solar radiation (S), and leaf temperature [T] (unitless)

From the equation above, the environmental preserver F(S, T) is the function of the solar radiation and temperature, and the environmental preserver F(S, T) for isoprene, monoterpene, and other VOCs are calculated by the equation, proposed by Guenther et al. [19].

BEIS2 calculates the solar elevation angle from the Julian day of the targeted day, the latitude and the longitude, time (LST) of the targeted area by the equation proposed by Iqbal [21] and known as the ASHRAE algorithm; and it considers the vapor amount, zenith angle, cloud cover, etc., and then it estimates 50% of the total solar radiation with PAR (Photosynthetically Active Radiation).

3. Photochemical Modeling

In this study, to estimate the effect of the present condition modeling, air materials and BVOCs emission from natural forest, we calculated the emission of BVOCs, using BEIS2 per 4 km×4 km grid about the area (domain-I) including some areas of GyongSang province in the center of Daegu. We estimated the ozone concentration applying UAM-IV, and to estimate the effect of BVOCs emission from city forest to the ozone concentration, we calculated BVOCs emission per 1 km×1 km grid about Daegu city area (domain-II) and we planned UAM.

3-1. Modeling Domain and Terrain Data

In this study, we selected the Daegu megalopolis of which the green dimensions are increased from 100.73 km^2 (1995) to 138.29 km^2 (2000) as a result of "Making Green Daegu" as an assay area; we set up an urban forest to the forest, bringing up in the Daegu city planning zone (919.62 km^2), according to the definition of the forestry administration research society [22] and Korea Rural Economic Institute [23].

Domain-II is a territory of 40 km×48 km (the standard of the eastern part origin TMX 139-179 km, TMY 233-281 km) including Daegu city planning zone, and the size of the grid is set up as 1 km× 1 km, and we divided it to 5 stairs vertically.

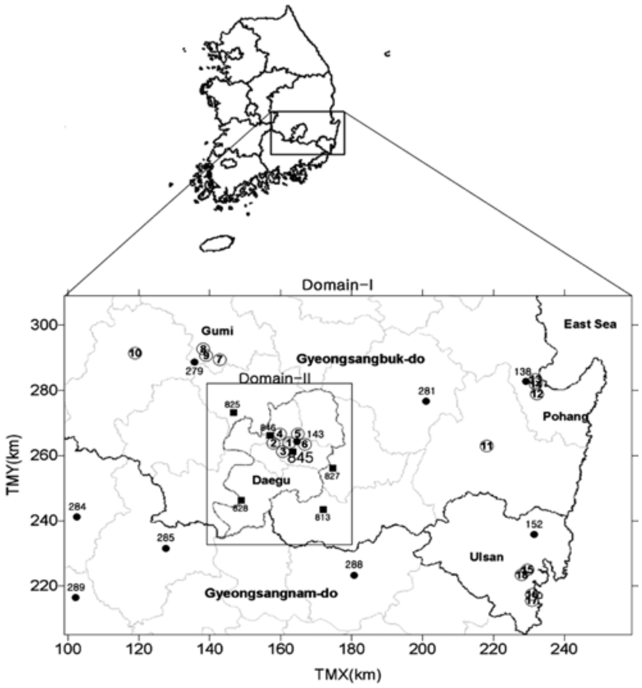


Fig. 1. Air quality monitoring sites (○), surface weather stations (●), and automatic weather stations (■) in the modeling domain.

Domain-I is the territory including GyongBuk and GyongNam partial area and Ulsan city in the center of Daegu city; the origin is longitude 127.889 degrees, latitude 35.336 degrees (the standard of the eastern part origin TMX 99,000, TMY 205,000), and the size of grid is set up as 4 km×4 km, and we divided it into 5 stairs vertically. In domain-I, a total of 18 automatic air quality monitoring stations including 6 of Daegu city and 4 of Ulsan city is being operated, and 9 SFC (Surface Weather Station) and 1 upper weather station are being operated; and in domain-II, 6 automatic air quality monitoring stations are being operated, and 1 SFC and 6 AWS (Automatic Weather Station) are being operated (Fig. 1).

Relatively high mountains are located in the northern area and southern area of Daegu city, western area of Ulsan city, northern·western area of Pohang city. Especially Daegu city is a form of inner basin that Palgong mountain is located in the northern area, Bisel mountain in southern area, and gentle hill areas in eastern·western areas.

UAM needs data about the height of the territory, the land use and surface roughness, etc., and it uses surface roughness and dry deposition variables fixed per land use. In this study, we constructed topographical data of elevation per grid and land use, using the topographical map published by National Geographic Information Institute, and the degree of green naturalness of the Ministry of Environment.

3-2. Modeling Period

The modeling Period of Domain-I is selected to be June 27th of which the ozone concentration in the 6 air quality monitoring stations of Daegu showed a high in 1999 when the emission research of anthropogenic pollutants were inclusively carried out and the day before, and the early spin-up period was planned to be 24 hours from midnight of June 25. to 23 o'clock of June 27. For Domain-II, it was planned from midnight to 23 o'clock of June 27, 1999 and July 4, 2000 when a high ozone concentration occurred in Daegu city, and the spin-period was early 10 hours, from 10 o'clock to 23 o'clock,

3-3. Anthropogenic Emission

For the emission data of NOx and anthropogenic VOC, we used the data, estimated at the time of establishing Daegu city air improvement practice plan of 1999.

The anthropogenic NOx emission of Domain-I is about 686 ton/day. Mobile sources take about 28.4% of the anthropogenic NOx emission, 1-3 class of point sources take about 31.4%. The anthropogenic NOx emission of Domain-II is about 108.9 ton/day, and mobile sources take about 68.3%.

The anthropogenic VOCs emission of Domain-I is about 385 ton/day, mobile sources take about 38.6%, and paint takes 30.9%. The anthropogenic VOCs emission of Domain-II is about 121.8 ton/day, mobile sources take about 32.2%, and paint and textile mills take 22.2%, 12.8% respectively.

The anthropogenic VOCs emission sources are classified per emission sources, CB-IV materials according to SPECIATE (EPA's Air Emissions Species Database, version 3.0) of U.S. EPA and the propositions of Carter [17]. For VOCs emission from textile establishments like tenter, coating, the process of dyeing, we lumped VOCs material measurement data [24] about the emission sources. From automobiles and paint, anthropogenic VOCs materials are mainly emitted; from paint, PAR (paraffin carbon bond), TOL (toluene), XYL (xylene) are mainly emitted, and VOCs emissions from automobiles are mostly PAR, XYL, TOL, ETH (ethene).

3-4. Meteorological Data

In this study, we used DWM (Diagnostic Wind Model) which produces 3D wind fields, and we also used SFC and AWS measurement data. DWM calculates the effect by topography, inclines, obstacles, and estimates vertical wind speed with executing the interpolation process of inputted wind data. It minimizes the diffusion of wind from 3D direction according to the law of conservation of mass, and it finally calculates the wind fields.

For mixing height, we calculated a mixing height per hour using Holzworth method and RAMMET. For surface pressure, we calculated the density of vapor using the measurement data of surface weather station and the equation proposed by McRae (1908). For the upper part of mixing height and the temperature gradient of the lower part, we estimated them using the mixing height produced by RAMMET and temperature distribution per altitude, and we calculated NO_2 photolysis constant using SUNFUNC, prprocessing program of UAM.

3-5. Initial Condition and Boundary Condition

U.S. EPA recommends to use ROM (Rgional Oxidant Model) in order to calculate the early period of UAM and the input data of a boundary condition. In this study, we set up the early concentration of O_3, NO_2, CO per station, using the data of automatic air quality monitoring station of the planning date, midnight, and we estimated the early concentration per grid, interpolating by the law of the inverse proportion of distance. The initial concentration of VOCs and other pollutants, and the concentration of domain-I boundary are estimated with reference of the data of Morris etc. [25], Jefferies (1996), and the boundary conditions of domain-II are used as present condition modeling result.

4. Biogenic VOCs Emission

BEIS2 needs temperature, wind speed, PAR (photosynthetically active radiation) in order to calculate the emission of BVOCs. In this study, we used the weather preprocessing program (TMPRTR) of UAM which produces weather data per grid, interpolating found weather data and the lowest grid temperature and wind speed of every hour produced from DWM. PAR is calculated internally in BEIS2, and to calculate PAR, we input the latitude, longitude, cloud covers of the targeted area.

4-1. Natural Forest Emissions

In BEIS2, the vegetation is classified into 127 species to use the emission variable per vegetation, and the data of vegetation is input by an area per vegetation in each grid. In this study, we used land use type of the targeted area by using the degree of green naturalness of the Ministry of Environment, and we used vegetation data using data of current vegetation degree. The degree of green naturalness is classified into 11 grades on the basis of the age of a tree and the succession stages.

The degree of current vegetation represents a vegetation distribution dividing deciduous latifoliate trees, coniferous trees, plantation forests, grasslands. The vegetation of Korea and USA is different, so in order to apply BEIS2, we reclassified the current vegetation degree to make it suitable for the vegetation classification of BEIS2. On the basis of land use by the degree of green naturality, we estimated the distribution per grid§″vegetation using current vegetation degree, and when a vegetation created a stock, we assumed that the dominant species, the highest population of concentration, frequency distribution.

4-2. Urban Forest Emissions

In the Daegu city plan zone, city natural parks (mountain in front), natural parks (Palgong mountain, Bisel mountain), vicinity parks (53 places), athletic parks (1 place), resorts (2 places), children's parks (286 places) are constituted, and apart from them, there are street trees, a strip, green establishments as landscape architecture trees. Except for Palgong mountain, Bisel mountain, mountain in front, there are 24 small and big mountains like Chonryong mountain (794 m) and Waryong mountain (300 m).

In this study, we classified urban forests as cultured trees and non-landscape woody plants. Street trees and landscape trees are of landscape woody plants, and the trees and forests in a park and resort are of non-landscape woody plants, but we included the trees in a children's park, which is a small establishment among parks and resorts to landscape woody plants. Compared to non-landscape woody plants, cultured trees are small in amount and distribution area, so it emits BVOCs a little, but it could directly damage the human body by the ozone concentration since it is close to cities and citizens.

We calculated the emission of BVOCs, dividing city natural parks, natural parks, etc. that are decided to be expressed as vegetation in the current vegetation degree, and children's parks, street trees, etc. that are decided not to be shown in it. Parks, resorts, forests, etc. (non-landscape woody plants), expressed in the current vegetation degree are estimated a distribution area per vegetation about each grid (1 km×1 km), and the emission of BVOCs per grid is estimated by using BEIS2. Street trees, green establishments, etc. (landscape woody plants) which are not shown in the current vegetation degree are estimated by the quantity per tree kinds. They are assigned per grid, after the emission of BVOCs is calculated by using BEIS2.

Cultured trees can be largely divided to street trees, landscape trees, trees of children's parks, and landscape trees are made up strips, green establishments, waterside parks. In Daegu city plan zone, there are total 3,442,000 clumps, and among them, 457,000 clumps, 13.3%, come under arbores.

In Korea forest, conifer trees are mainly seen, but as landscape woody plants, deciduous trees (including deciduous coniferous tree), Platanus occidentalis L., Zelkova serrata Makino, Ginkgo biloba L., etc. are mainly planted.

In this study, we calculated the emission of BVOCs, applying the emission variable of BEIS2 per species for the street trees, available for finding out the amount data by species; and about landscape trees which do not have the amount data by species and trees in children park, we assumed that a representative species is planted, and we calculated the emission of BVOCs using BEIS2.

To calculate the emission of BVOCs by non-landscape woody plant, we calculated the distribution area per vegetation using a current vegetation degree on the basis of land use by green naturality like natural forests, and when a vegetation creates a stock, we assumed that dominant species distributed.

RESULT AND DISCUSSION

1. Biogenic VOCs Emission using BEIS2

1-1. Natural Forest Emissions

For the dimensions and the component ratio per domain-I land use of the targeted area, 55.9% consist of forested areas, and farm lands, city areas, water areas take 27.3%, 4.8%, 12.1%, respectively. In forested areas, conifers mainly distribute (about 78.3%), and deciduous broad-leaved forests take about 21.5%. Plantation forests, which take about 20.5% of forested areas, are mainly constituted of conifers (about 92.1%).

For the distribution dimensions per vegetation stock, the distribution dimensions of Pinus densiflora, Pinus rigida, Pinus koraiensis, Pinus thunbergii which are main emission sources of monoterpene take about 76.5%, most of forested area, and the component ratio of deciduous tree, Q. mongolica, 8.9%, Q. variabilis, 7.6%, Q. acutissima, 1.4% which are deciduous trees, emission of mainly isoprene was relatively low.

For the result of distribution dimensions, emission variable, LAI (Leaf Area Index) per BEIS2 vegetation code, the distribution dimensions of Pinu (pine) showed large, and the one of Quer (oak) was comparatively large. Pinus is estimated as a main emission source of monoterpene because the emission variable of monoterpene is big, the distribution area is large, and Quer is estimated as a main emission source of isoprene for the same reason.

About total emission of BVOCs per sources to domain-I, the emission of monoterpene is the most, and isoprene and other VOCs follow, and this is similar to the emission of natural VOC, estimated by Kim et al. [26]. This can be decided because conifer trees are distributed in the forested area of domain-I (about 59.4%), the area of deciduous trees is relatively small (about 19.9%), the distribution area (76.5%) of pinus trees, which are the main emission sources of monoterpene, is relatively higher than the one of deciduous forest which emit mainly isoprene.

The emission of BVOCs per day is the most on June 27th when the mean temperature of domain-I is high and the cloud cover is little, and especially for isoprene, the emission of June 27th was 2.0 times and 2.2 times more than June 25th and 26th each. This is because the emission rates of isoprene and monoteprene increase exponentially to leaf area temperature, and the emission of isoprene has a logarithmic relation with solar radiation [11,27].

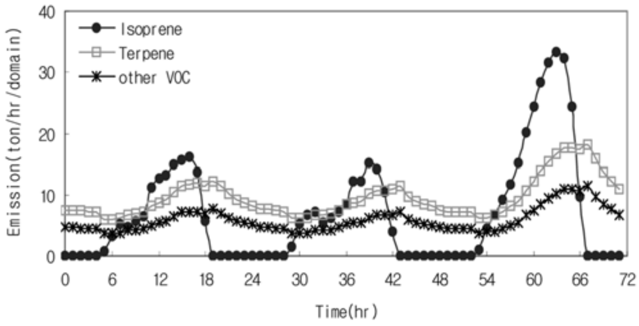


Fig. 2. Hourly variation of BVOCs emission from the modeling domain-I.

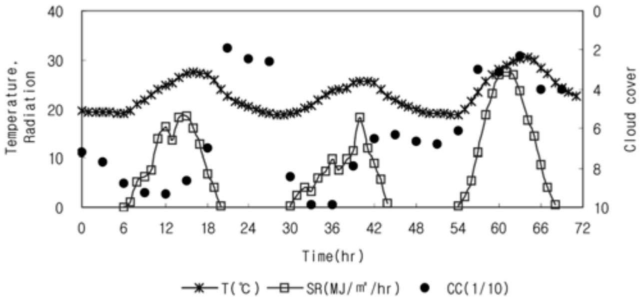


Fig. 3. Hourly variation of meteorological parameters during the modeling period.

1-1-1. Hourly Variation of BVOCs Emission

Fig. 2 represents hourly variation of BVOCs emission of the planning period, using BEIS2, and Fig. 3 represents hourly temperature, solar radiation, cloud covers of the ground weather monitoring station during the same period.

BVOCs emission shows significant daily variations, and monoterpene and other VOCs are similar to the daily pattern of temperature, and isoprene has similar variations to the solar radiation (or the reciprocal of the is not emitted until sunrise, and after sunrise, the emission increases and it shows the most, and after sunset it is not emitted. This is because we do not consider that isoprene is emitted when there is no solar radiation, since isoprene can emit by thermal stress relief mechanism [28].

For BVOCs emission of Domain-I, monoprene emission is the most in consideration of daily emission, but isoprene emission is high in the daytime; the reaction is very high (the atmosphere life reaction to OH radical is 1.8 hr), photochemical ozone creation potentials (POCP=109.2 [29]) and maximum reactivity increases (MIR =9.1 [17]) are high, so the contribution rate to the maximum ozone concentration that is created at late afternoon is estimated relatively high in isoprene.

1-1-2. Spatial Distributions of BVOCs Emission

Fig. 4 shows spatial distributions of BVOCs emission in domain-I, and other VOCs emission is similar to the spatial distributions of

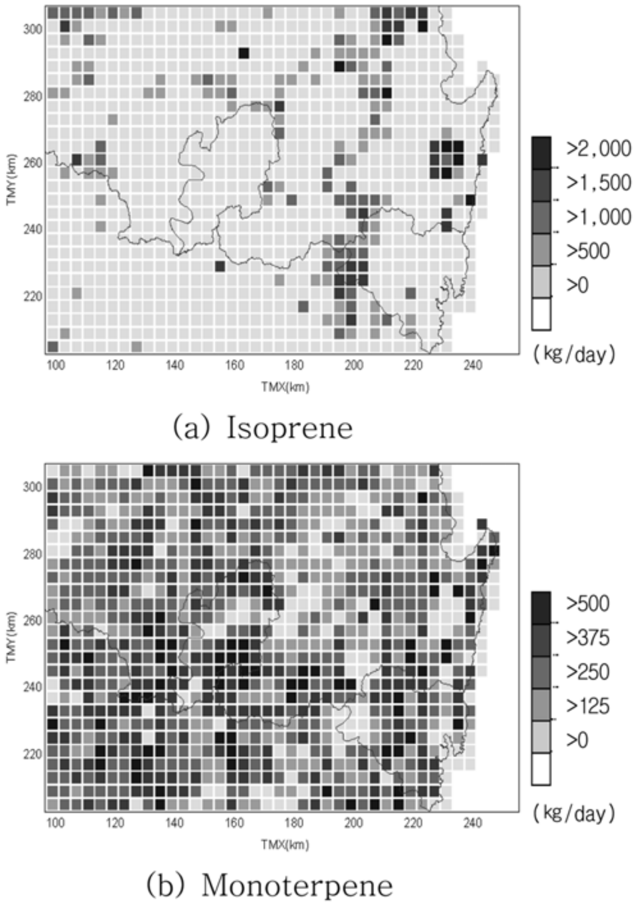


Fig. 4. Spatial distributions of biogenic isoprene (a), and monoterpene (b) emissions (ton/day/domain) in 27 June, 1999.

monoterpene. While monoterpene is emitted generally in domain-I, including Daegu city, isoprene is emitted considerably in the boundary aralso ea of Pohang and Gyongju, the northern area of Pohang, and also in the boundary area of Ulsan city and Gyongsang south·north province. The daily emission in domain-I is comparatively high in monoterpene, but the maximum emission of the unit grid (4 km×4 km) showed relatively high in isoprene of which the emission distribution is concentrated in partial areas. Therefore, in view of contribution to ozone, monoterpene emission affects generally in the modeling domain, but isoprene would affect locally.

1-1-3. BVOCs Emission Lumping

BVOCs emission produced by using BEIS2 is used in UAM modeling according to EIIP [30], and BVOCs emission per CB-IV sources of June 27th is like Fig. 5. The emission per CB-IV sources in modeling domain showed in the order of PAR (paraffin carbon bond), ISOP (isoprene), ALD2 (high molecular weight aldehydes), OLE (olefinic carbon bond), and ISOP emission took about 37.8% of BVOCs emission per sources.

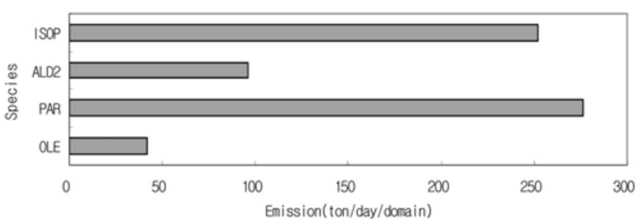


Fig. 5. BVOCs emissions profiles represented as the model species in the CB-IV mechanism in 27 June, 1999 for domain area.

1-2. Urban ForestEmissions

1-2-1. Emission of the Cultured Trees

In Daegu city, 33 kinds of about 143,000 street trees are planted, and Platanus occidentalis L. (26.4%), Ginkgo biloba L. (24.0%), Zelkova serrata Makino (17.9%), Prunus yedoensis Matsunura (9.9%) take about 78.2% of all, and especially the street trees of Platanus occidentalis L. and Ginkgo biloba L. (about 50.5%) preponderate too much to the two trees.

Platanus occidentalis L., etc. present an emission variable in BEIS2, but in the BVOCs emission list of BEIS2, gloBEIS3, there is no emission variable about Ginkgo biloba L., Zelkova serrata Makino, Chionanthus retusa, and Japanese pagoda tree. So about these kind of trees, we divided them into similar species or inclusive species of BEIS2 vegetation code. In deodar, coniferous trees, monoterpene is emitted mostly, and platanus, Ginkgo biloba L., Japanese pagoda tree, which are deciduous tree (including deciduous coniferous tree), isoprene is mainly emitted. Especially, platanus is emitted to a large extent, and it has a big emission variable of isoprene, so it would be a main emission source of isoprene.

In this study, we divided into an arbor and a shrub, to yield BVOCs emission of cultured trees using BEIS2. We also assumed the planting density of an arbor to 0.1 bon/m^2 in consideration of forest planting density and landscape planting density, and for a shrub, we assumed it the same as the planting density 1.0 bon/m^2 authorized in the regulations of Seoul city.

As BVOCs emission of cultured trees produced by using BEIS2 is isoprene 65.4 kg/day, monoterpene 76.2 kg/day, other VOCs 80.0 kg/day, BVOCs, emitted from cultured trees is 0.7-2.2% of BVOCs emission, emitted from non-landscape woody plants. We can assume that isoprene is emitted mainly from street trees, and monoterpene and other VOCs mostly from landscape trees, trees in children's parks, and shrubs.

1-2-2. Emission of the Non-cultured Trees

Planting a forest in Daegu city plan zone took about 3.2% of all the city forest. Pinu (Pine) showed the largest distribution area, and Pinu is assumed as a main emission source of monoterpene, because its emission speed of monoterpene is high. The distribution area of Quer (oak) showed comparatively small, but the emission speed of isoprene is high, so it is assumed to emit relatively much isoprene. BVOCs of non-landscape woody plants, calculated by using BEIS2 emitted mainly monoterpene, and isoprene was presumed to 5,128 kg/day, about 28% of monoterpene.

1-2-3. Emission of Urban Forest

Table 1 shows BVOCs emissions from natural forests and city forests of domain-II on June 27th, 1999. Those emissions were similar, and in case of city forests, BVOCs were mostly emitted from non-landscape woody plants. While monoterpene (more than 50% of all BVOCs emission) was emitted mostly from natural forests and non-landscape woody plants, and isoprene emission takes a low rate (15-20%), from landscape woody plants; isoprene and monoterpene were emitted similarly. This is because most forested areas consist of coniferous trees, but deciduous trees were planted for land-

Table 1. BVOCs emissions in the modeling domain-II on 27 June, 1999

Sources		BVOCs emission (kg/day)			
		Isoprene	Monoterpene	Other VOCs	Total
Total		14,180	41,057	23,556	78,793
Natural forest		7,798	19,000	10,967	37,764
Urban forest	Total	6,382	22,058	12,589	41,029
	Non-cultured trees	6,244	21,899	12,422	40,566
	Cultured trees	138	159	166	463

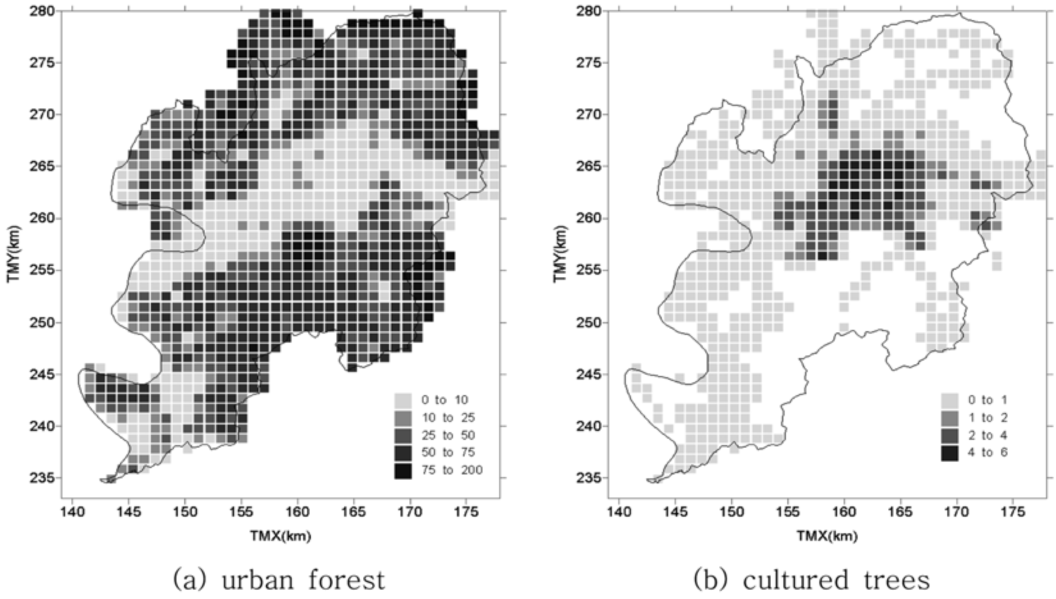


Fig. 6. BVOCs emission (kg/day/km^2) from urban forest (a) and lndscape woody plants (b) on 27 June, 1999.

scape use like street trees.

Fig. 6 shows spatial distributions of BVOCs emission (June 27, kg/day/km^2) from natural forest and landscape woody plant. BVOCs of city forest are emitted mainly from outer northern and southern areas of Daegu city, but BVOCs from cultured trees are distribute mainly in cities.

2. Sensitivity of Ozone Concentration to VOCs and NOx

The direct emission sources affecting the creation of ozone and extinction reaction are NOx and VOC. We understood air quality in view of ozone by analyzing sensitivity of ozone concentration to NOx and VOCs emission variations in the research areas.

To understand sensitivity of ozone concentration according to the emission variations, we planned a case of increasing anthropogenic VOCs emission of domain-I to 25%, 50%, respectively, and a case of increasing anthropogenic NOx emission to 25%, 50%, respectively.

Fig. 7 shows changes of the mean value of maximum ozone concentration per day in Manchondong, Bokhyundong, Nowondong according to anthropogenic emission changes. While anthropogenic VOCs emission and daily maximum ozone concentration have a positive correlation, anthropogenic NOx emission and daily maximum ozone concentration have a negative correlation. So in Daegu city, VOCs operate as limited chemical species to ozone concentration, and air quality can be a VOC-limited status. To reduce the

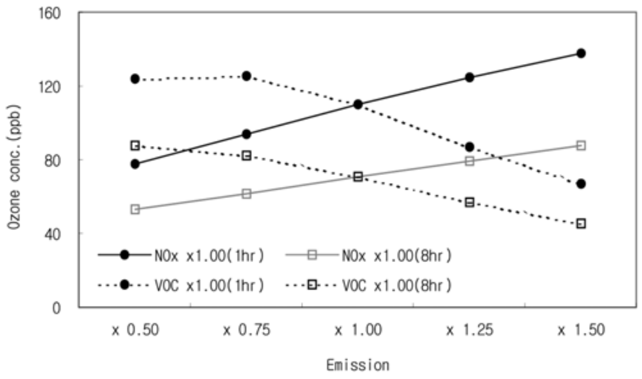
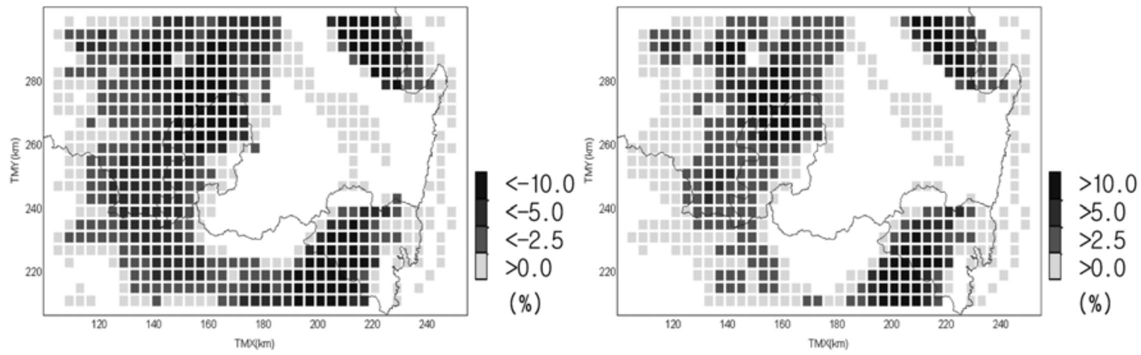


Fig. 7. Sensitivity of daily maximum 1-hr ozone concentration for Manchon, Bok-hyeon and Nowon in Daegu to anthropogenic VOCs and NOx emission on 27 June, 1999.

ozone concentration of Daegu city, VOCs emission would be diminished.

About the mean change rate of ozone concentration according to the emission changes, when anthropogenic VOCs emission increased (decreased) 25%, the mean maximum ozone concentration of 1 hour and 8 hours increased (decreased) about 12%, respectively, and when anthropogenic NOx emission increased (decreased) 25%,



(a) BVOCs 50% decrease (b) BVOCs 50% increase

Fig. 8. Percent change in ozone concentration (15LST) simulated with UAM from base case to a varied BVOCs emission (varied BVOCs emission - base case) for 27 June, 1999.

the mean maximum ozone concentration of 1 hour and 8 hours increased (decreased) about 17%, respectively.

3. Effect of Natural Forest BVOCs Emission to Ozone Concentration

3-1. Sensitivity of O_3 Concentration to BVOCs Emissions

We applied UAM and analyzed the effect of BVOCs emission from the vegetation of modeling domain to ozone concentration. We planned that BVOCs emission of every material from domain-I increases 25% and 50% in time and space, and we used the BVOCs emission data, applied BEIS2.

The changes of night ozone concentration were rear, even though BVOCs emission increased, and when BVOCs emission was decreased in the daytime, the ozone concentration of Daegu, Gumi, Pohang and Ulsan area was decreased; and when BVOCs emission was increased, the ozone concentration was increased.

This is because isoprene emission does not change, even though BVOCs emission changes since isoprene is not produced at night; ozone is not produced because a photochemical reaction does not proceed, and only O_3 extinction reaction by NO-titration exists, and it is controlled by NO concentration.

In Daegu area, the changes of ozone concentration according to the changes of BVOCs emission changes were significant, and in Pohang area, they were very few. When BVOCs emission changed, ozone concentration increased high in a high concentration domain, and this is because BVOCs, especially isoprene emission, was high in the afternoon when photochemical reaction is active, so it is estimated that BVOCs emission affects the high concentrated ozone production.

When BVOCs emission increased 25% and 50%, we analyzed the effect of ozone concentration per grid, calculated by UAM. When BVOCs emission increased 25-50%, ozone concentration did not increase in about 30% of all grids or it showed a contrary change to BVOCs emission changes; but in most grids, BVOCs emission and ozone concentration showed a correlation. We estimated that when BVOCs emission decreased 50%, about 3.5 ppb of ozone concentration decreased in about 70.7% of all grids, and when BVOCs emission increased 50%, about 2.9 ppb of ozone concentration decreased in about 63.6% of all grids.

When BVOCs emission increased or decreased 50%, the 15 hour mean ozone concentration of modeling domain increased 1.6 ppb or decreased 2.3 ppb, so in view of the whole modeling domain, the effect of BVOCs emission changes to ozone concentration could not big. But when BVOCs emission increased, it had a considerable effect on anthropogenic NOx emission sources and to the ozone concentration of populated urban areas (Daegu, Gumi, Pohang, Ulsan). Especially in the northern part of Daegu city, the ozone concentration was affected very much by BVOCs emission. We estimated that when BVOCs emission increased or decreased 25% (50%), the 15 hour ozone concentration of northern part increased or decreased about 5-10 ppb (10-25 ppb), Gumi city was 2-5 ppb (5-10 ppb), Pohang and Ulsan city was 2 ppb (5 ppb).

3-2. Effect of Conifer Trees and Deciduous Trees on Ozone Concentration

In the forested area of domain-I, conifer trees (about 78.3%) are mainly distributed, deciduous trees take about 21.5% of the forested area. While conifer trees are largely distributed in the forested area, deciduous are mainly distributed in the eastern area of the targeted domain.

The effect of BVOCs from conifer trees to ozone concentration is calculated as below.

$$\text{Conifer tree effect (ppb)}=[O_3]_{conifer\ tree\ only}-[O_3]_{BVOCs=0}$$
$$\text{Deciduous tree effect (ppb)}=[O_3]_{deciduous\ tree\ only}-[O_3]_{BVOCs=0}$$

The bottom word, conifer (deciduous) tree, only means BVOCs emission from conifer trees (deciduous trees), and BVOCs=0 means no consideration of BVOCs emission.

BVOCs emission from confer and deciduous trees increased the 15LST mean ozone concentration of targeted domain about 3 ppb each, and the maximum increased amount was about 40 ppb and 50 ppb, respectively. BVOCs emission from conifer and deciduous trees affects mainly the ozone concentration of the northern area of Daegu, and we estimated that it affects the ozone concentration of the western area of Ulsan and the northern area of Pohang. Fig. 9 shows the effect of conifer and deciduous trees on the hourly ozone concentration of Daegu area (Bokhyundong, Manchondong Nowondong) of June 27, 1999.

When we do not consider BVOCs emission from natural forests, the daily maximum ozone concentration of the Daegu area was about 59 ppb. In the condition of existing anthropogenic emission, conifer and deciduous trees increased ozone concentration about

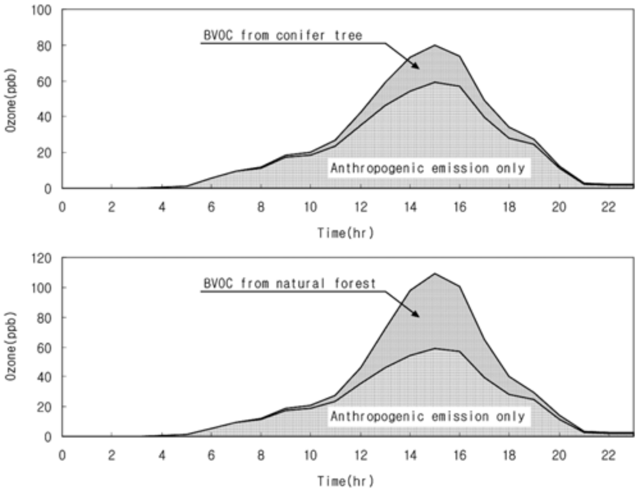


Fig. 9. Effectiveness of BVOCs emission from conifer (upper), deciduous (lower) on ozone concentration at Daegu region for 27 June, 1999.

21 ppb and 29 ppb respectively at most; BVOCs emission from natural forest (conifer trees+deciduous trees) is estimated to cause 50 ppb, about 85% of daily maximum ozone concentration by an anthropogenic emission. While an anthropogenic emission considerably affects the ozone concentration of early morning and late afternoon, BVOCs emission affects mainly the ozone concentration of afternoon, that is, high concentrated ozone production.

4. Effect of Urban Forest BVOCs Emission on Ozone Concentration

Table 2 shows the effect of urban forest BVOCs emission on the ozone concentration of Daegu city of June 27, 1999, and the mean value and the maximum value of daily maximum ozone concentration per 935 grids (1 km×1 km) of Daegu city.

When urban forest BVOCs emission is not considered (Base case), the mean value of daily maximum ozone concentration per grid was 70.4 ppb and the maximum value was 119.9 ppb. When it is considered (Urban forest BVOCs), the daily maximum mean concentration of Daegu city was 73.6 ppb, so urban forest increased the daily maximum mean ozone concentration of Daegu about 3.2 ppb (4.6%). When urban forest is considered, the maximum value of daily maximum ozone concentration of Daegu was 128.0 ppb, increased about 8.1 ppb (6.8%). The effect of daily maximum ozone concentration on the mean value and the maximum value was mostly by non-landscape woody plants (the mean value 3.0 ppb, 91.6%, the maximum value 6.6 ppb, 81.5%), and the effect of landscape woody plants (0.3 ppb, 1.5 ppb) to the daily maximum ozone concentration of Daegu city was relatively low (8.4%, 18.5%).

Urban forest affects mainly the ozone concentration of the eastern area (Donggu, Susanggu) of Daegu city, and it is insignificant to the southern area (Dalsunggun). Urban forest increases daily maximum ozone concentration of the center part of Daegu city about 2-7 ppb, and it contributes 12 ppb at most in the eastern area.

The regional difference of the effect of urban forest to ozone area is estimated by a spatial distribution and wind of emission sources; especially, the effect of urban forest to the ozone concentration of the eastern area of Daegu city can be explained by the north·west wind which was main in the daytime, anthropogenic NOx, VOCs which are centered in the center part of Daegu city, and northern BVOCs emission.

5. Estimation for Cultured Trees Alteration on Ozone Concentration

Carter (1994) calculated that the MIR (Maximum Incremental Reactivity) to estimate a reactivity of VOCs source, related to ozone creation, MIR of isoprene, α-pinene and β-pinene which are emitted mainly from the vegetation was, respectively, 9.1, 3.3 and 4.4 g O_3/g VOC. Using the emission speed of isoprene and monoterpene, biomass, and MIR of Carter [17], Benjamin and Winer [31] produced OFP (Ozone-Forming Potential) per 308 species under the average summer weather condition from SoCAB (California south coast air basin), and each species is divided to 3 groups (low, medium, high) according to OFP, the OFP of maple, Zelkova serrata Makino, Ginkgo biloba L. is low, and the OFP of Platanus occidentalis L., oak, Populus devidiana was high.

In Daegu city, total cultured trees as urban forest are 3,442,000 trees, about 13.3%, 457,000 stumps are trees, arbors. For landscaped woody forest, as street trees, 143,000 stumps of 33 species like Platanus occidentalis L., Ginkgo biloba L., Zelkova serrata Makino are planted, and as landscape trees and trees in the children's park are representatively 7 species like Pinus densiflora Sieb. et Zucc., Ginkgo biloba L., and 8 species such as Pinus densiflora Sieb. et Zucc., Cedrus deodara (Ruxb.) Loudon.

In this study, to find the effect of species selection of cultured trees to ozone concentration, we planned the case of unchanged species and amount of landscape woody plants (Base case : current status), the double increased case of the cultured trees amount (DoubleTRE : planted a cultured trees additionally), all planted with Zelkova serrata Makino as the species of landscape woody plant (Low OFP : planted low OFP species) and all planted with Platanus occidentalis L. as the species of landscape woody plants (High OFP : planted the species with a high ozone creation ability). There was no effect of temperature by the amount changes of landscape woody plants; we assumed that additional vegetation amount has the same spatial distribution with the +present.

Table 3 shows the mean value and the maximum value of 1 hour maximum and 8 hour maximum ozone concentration of Daegu city

Table 2. Contribution of urban forest to daily maximum ozone concentration (ppb) in Daegu metropolitan city cells on 27 June, 1999

	O_3 (ppb)		Urban forest BVOCs effect (ΔO_3)		
	Base case	Urban forest BVOCs	Landscape woody plant	Non-landscape woody plant	Total
Average[a]	70.4	73.6	0.3 ppb (0.4%)	3.0 ppb (4.2%)	3.2 ppb (4.6%)
Maximum[b]	119.9	128.0	1.5 ppb (1.3%)	6.6 ppb (5.5%)	8.1 ppb (6.8%)

[a,b]Means average and maximum of peak ozone concentrations in each cells including Daegu metropolitan city, respectively.

Table 3. Average and maximum change in 1-hr and 8-hr peak ozone concentrations in Daegu metropolitan city cells for cultured trees scenarios

Scenarios	1-hr peak				8-hr peak			
	O_3 (ppb)		ΔO_3 (ppb)		O_3 (ppb)		ΔO_3 (ppb)	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Base case	73.6	128.0			58.9	103.9		
DoubleTRE	73.8	128.6	+0.1 (0.1%)	+0.6 (0.5%)	59.0	104.1	+0.1 (0.1%)	+0.2 (0.2%)
Low OFP	73.4	126.6	−0.3 (0.4%)	−1.4 (1.1%)	58.8	103.7	−0.1 (0.1%)	−0.2 (0.2%)
High OFP	74.2	131.3	+0.6 (0.8%)	+3.3 (2.6%)	59.3	105.2	+0.4 (0.7%)	+1.3 (1.3%)

according to the changes of species and amount of landscape woody plants. We estimated that when the amount and species of cultured trees do not change (Base case), the mean value and the maximum value of 1 hour maximum ozone concentration of Daegu city were 73.6 ppb and 128.0 ppb, which exceeds the NAOS (National Ambient Ozone Standard) in 115 grids (12.3%). The mean value and the maximum value of 8hour maximum ozone concentration were 58.9 ppb and 103.9 ppb, which exceeds the NAOS in 346 grids (37.0%). We estimated that when the number of cultured trees is increased two times (DoubleTRE), the mean value and the maximum value of 1 hour maximum ozone concentration increased 0.1 ppb (0.1%) and 0.6 ppb (0.5%) each, for 8 hours, 0.1 ppb (0.1%) and 0.2 ppb (0.2%). And for DoubleTRE, the amount of excess grid increased 3 grids (0.3%) at 1 hour average, 1 grid (0.1%) at 8hours average. So ozone concentration and NAOS excess grid amount could not increase even though the vegetation amount increases keeping the current species.

When a species of cultured trees was changed with Zelkova serrata Makino of which the ozone creation ability is low (Low OFP), the mean value and the maximum value of 1 hour maximum ozone concentration decreased 0.3 ppb (0.4%) and 1.4 ppb (1.1%) respectively, and for 8hours, 0.1 ppb (0.1%) and 0.2 ppb (0.2%). In case of Low OFP, the 1 hour mean concentration decreased NAOS excess 6 grids (0.6%), for 8 hours, 2 grids (0.2%). Therefore, in consideration of DoubleTRE, the ozone concentration can be kept at the current level, even though the vegetation amount increased twice, changing the species of cultured trees to OFP low species.

We expected that when we changed the species of cultured trees with Platanus occidentalis L. of high ozone creation ability (High OFP), the mean value and the maximum value of 1 hour maximum ozone concentration increased 0.6 ppb (0.8%) and 3.3 ppb (2.6%), and for 8 hours, 0.14 ppb (0.7%) and 1.3 ppb (1.3%). In case of High OFP, the 1 hour mean concentration increased NAOS excess 9 grids (1.0%), for 8 hours, 8 grids (0.9%). So when high OFP species are planted additionally, it might cause a negative result in ozone concentration and NAOS excess grid amount increase.

CONCLUSION

In natural foresst and non-landscape woody plants, monoterpene (more than 50% of BVOCs emission) is mainly emitted, and the ratio of isoprene (15-20%) is low. This is because conifer trees, Pinus densiflora, Pinus rigida, Pinus koraiensis, Pinus thunbergii, etc. that emit mainly monoterpene as natural forest and non-cultured trees are mainly distributed (about 76.5%), and the ratio of decidouos tree, Quercus mongolica (8.9%), Quercus variabilis (7.6%), Quercus acutissima (1.4%) that emit mainly isoprene is relatviely low. Whereas, in landscape woody plants, isoprene and monoterpene emission was similar, because as street trees and landscape trees, deciduous trees like Platanus occidentalis L., Ginkgo biloba L., etc. are mainly planted.

We expected that in most grids, ozone concentration and BVOCs emission by natural forest have a correlation, and when BVOCs emission decreases 50%, daily maximum 1 hour ozone concentration in about 70.7% of all grids decreases about 3.5 ppb on the average; and when BVOCs emission increases 50%, the ozone concentration in about 63.6% increases 2.9 ppb on the average.

When anthropogenic emission is only considered, the daily maximum 1 hour ozone concentration of Daegu area of June 27, 1999 was about 59 ppb, and in consideration of BVOCs emission, conifer trees and deciduous trees increased 21 ppb and 29 ppb each of the maximum ozone concentration, so BVOCs emission would induce 80% of daily maximum ozone concentration by anthropogenic emission.

Urban forest increases the mean value of daily maximum ozone concentration about 3.2 ppb (4.5%), and it is mostly by a large number of non-landscape woody plants, and small amount of cultured trees relatively does not have much effect.

When the species of cultured trees are changed with low OFP Zelkova serrata Makino, 1 hour maximum ozone concentration decreases 1.4 ppb (1.1%), NAOS excess grid amount decreases 6 (0.6%), and when they are changed with high OFP Platanus occidentalis L., 1 hour maximum ozone concentration increases 3.3 ppb (2.6%), and NAOS excess grid amount increases 9 (1.0%). Thus, city ozone concentration would be decreased limitedly by selecting species in consideration of the contribution of BVOCs ozone concentration, emission from vegetation.

Recently, as an improvement tool for air quality, a huge city tree-planting has been conducted; but for big cities where automobiles, NOx main emission sources are concentrated, it is possible of VOC-limited status. And when a huge tree-planting operation is executed, it is considered that damage to the human body and the crops might be induced by ozone concentration increase and high concentrated ozone. Therefore, Zelkova serrata Makino of low OFP might be better as cultured trees rather than Platanus occidentalis L. of high OFP for a city tree-planting business.

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