

Analysis of the various Researches on the mechanism of airborne particulate matter's formation and conversion from ship's emission

Kim seoyoung (Korea Maritime Institute)

KMI 한국해양수산개발원
KOREA MARITIME INSTITUTE

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Highlight

Implications for preparing or upgrading the methodology for monitoring the movement and diffusion and impact of air pollutant emissions caused by port and ship activities

Comparative analysis of related domestic and foreign projects and research cases by major keywords

1. Emission data that can be used jointly in the Asian region is required
2. Calculation of domestic emission data in a denser space-time grid unit by applying a bottom-up model
3. When simulating movement diffusion by emission, compare and correct the results after simulation using multiple programs or different chemical mechanisms
4. When separately calculating including the port sector in national statistics, the classification system for combustible and non-combustible emission sources should be applied.

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Analysis of the various Researches on the mechanism of airborne particulate matter's formation and conversion from ship's emission

1. Research overview
2. Current status of domestic air pollutant emission regulations and policies
3. Comparison of recent research cases on air pollutant monitoring
4. Findings

01 Research overview

Air pollutant monitoring

Needs

01 Increased public concern due to the risk of air pollutants

- Affect lung function or increase the incidence of cancer
  → Air pollutants: emerged as a serious social problem
- Rising efforts to reduce air pollutants all around the world

02 Air pollutant monitoring & emission reduction policies

- Use air pollutant monitoring results to determine emission reduction policies
  → Improving the accuracy and efficiency of air pollutant emission reduction policies

※Air pollutant monitoring results: Emissions of pollutants, Movement and diffusion, Effects on receptor

01 Research overview

Air pollutant monitoring

Needs

03 Air pollutant monitoring

- Divided into three steps
  - → **Identify emission inventory** from the source into the atmosphere
  - → **Predict the concentration** of air pollutants in the atmosphere at the target point resulting from the **movement and diffusion** of discharged pollutants
  - → **Predict environmental and health impacts** resulting from emissions

Air pollutant Monitoring



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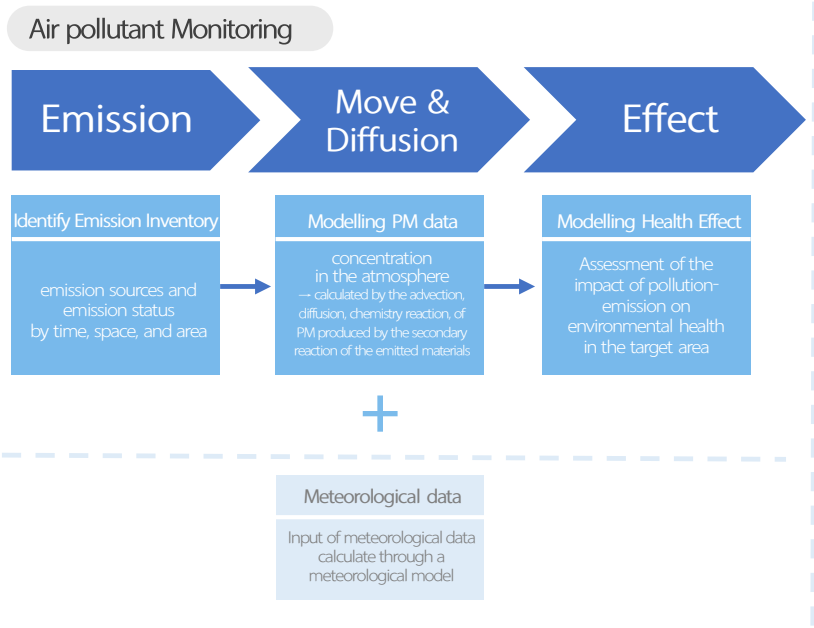

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- Results of the monitoring → used as the basic basis for policy development and application

Air pollutant Monitoring

Emission
Identification of emission sources and emission status by time, space, and area

Move & Diffusion
Identification of changes in concentration distribution due to emission by simulating the process of generation, movement, and diffusion of (ultra)fine dust caused by the reaction of emitted substances in the atmosphere

Effect
Identification of changes in environmental impacts of specific regions of emissions, movement and diffusion

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Deriving air pollution related policies/business

Target & optimal Solution
- → Thoroughly understand the problem
- → Apply sophisticated problem-solving methods
- → Determine the order of priority by policy and emission source

Development & Application
Develop and apply systematic policies and technologies

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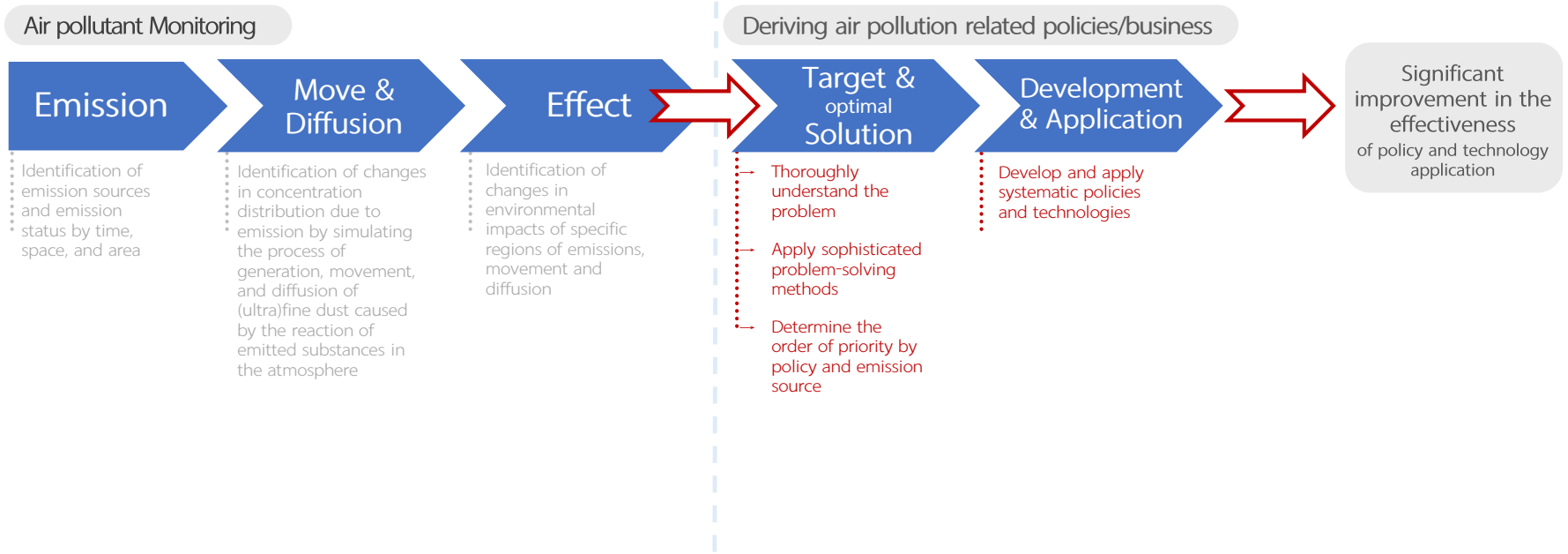

02 Current status of domestic air pollutant emission regulations and policies

Air pollution reduction laws

Needs

01 Special Act on the Reaction and Management of Fine Dust (2020.04.03)

- Establishment of a comprehensive plan for fine dust management
- Identification of emission sources

02 Clean Air Conservation Act (2022.03.25)

- Air pollutant emission regulation and emission investigation

03 Special Act on the Improvement of Air Quality in Air Control Zones (2023.04.03)

- Establishment of a basic plan for air environment management
- Management of the total amount of pollutants in the workplace
- Suppression of exhaust gas from automobiles, construction machinery, ships, etc.

Special Act on the Improvement of Air Quality in Port Areas (2020.09.01)

- Establishment of a comprehensive air quality improvement plan in port areas, etc.
- Management of emission sources and establishment of eco-friendly ports

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Only direct emission reduction

Insufficient regulations for actual monitoring

※ Monitoring: Port policy design, basic prerequisite for rethinking policy effectiveness

02 Current status of domestic air pollutant emission regulations and policies

Air pollutant monitoring

Needs

Current status of air pollutant monitoring in port area and ship sector

- Ideal process
  → establish an emission reduction policy to improve the environmental impact by utilizing the results obtained through the monitoring system.



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Air pollutant monitoring

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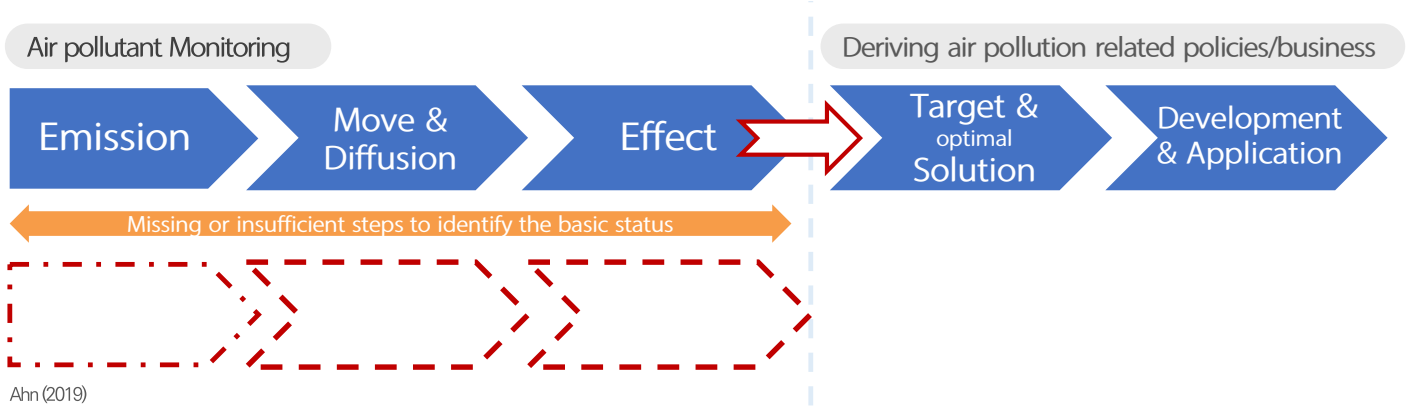
Current status of air pollutant monitoring in port area and ship sector

- Ideal process
  → establish an emission reduction policy to improve the environmental impact by utilizing the results obtained through the monitoring system.
- Insufficient basic status identification step through air pollutant monitoring



Ahn (2019)

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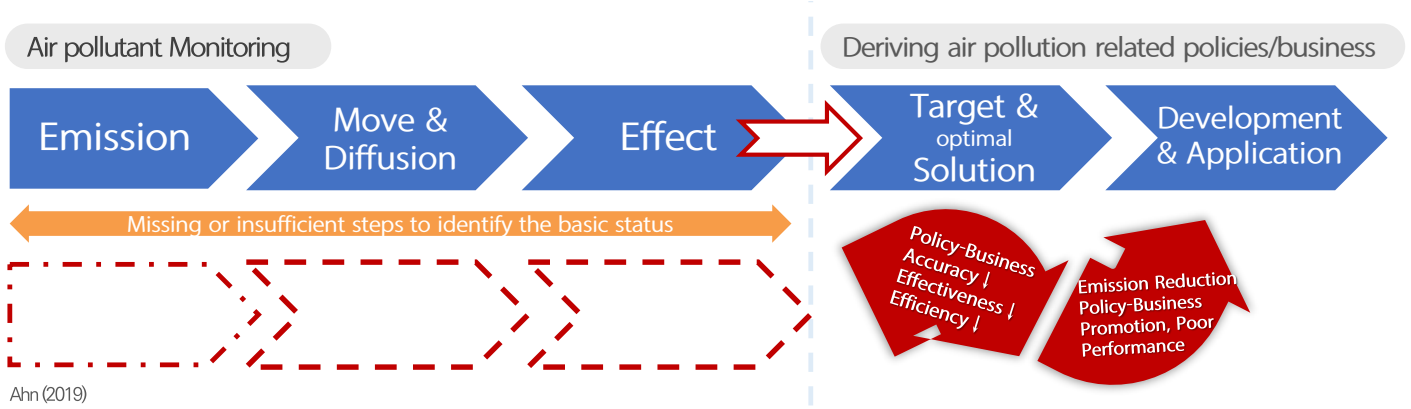
  → May decrease the accuracy, effectiveness, and efficiency of the policy



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Air pollutant Monitoring

Deriving air pollution related policies/business



- Clean Air Conservation Act (Surveys on Sources and Quantities of Emissions of Air Pollutants) & Special Act on the Reduction and Management of Fine Dust (Establishment and Operation of National Air Emission Inventory and Research Center)
  → Included regulate air environment management, about national air pollutant emission sources and emission calculations
- Efforts to identify the emission of convertible substances from emission sources, research progress, and advancement of emission factors
- Ports & Ships
  → Ports: Not included in the national statistics on air pollutant
  → Ships: Included, but low reliability
- In the case of ships, upgrading is continuously in progress, and ports are also expected to be included in the national statistics

02 Current status of domestic air pollutant emission regulations and policies

Air pollutant monitoring

Needs

Current status of air pollutant monitoring in ship sector

Emissions of pollutants from the source into the atmosphere

SCC	First-level classification of emission sources
1	Energy production
2	Non-industry
3	Manufacturing industry
4	Industrial process
5	Energy transport and storage
6	Solvent use
7	Road mobile sources
8	**Non-road mobile pollution sources**
9	Waste disposal
10	Agriculture
11	Other surface-pollutant source
12	Fugitive dust
13	Biomass burning

SCC	Second-level classification
1	Railways
2	**Ships**
3	Aircraft
4	Agricultural machinery
5	Construction machinery

SCC	Sub-category	Allocation
1	Passenger ships	Calculating annual emissions → Determine monthly allocation Allocate emission according to operation route ※ Outward bounder: limited activity data → do not calculate emission data
2	Cargo ships	Calculating monthly emissions for each port Allocate emissions to the sea grid by calculating emissions based on the route in case of allocation to the relevant city, county, and operation mode
3	Fishing vessels	Calculating annual emissions → Determine monthly allocation 5%: allocated to cities, towns and districts based on fishing ports 95%: allocated to sea emissions
4	Leisure vessels	Calculating annual emissions → Determine monthly allocation Allocated to spatial resolution cities and provinces using location information of domestic marina ports

Time Resolution: Monthly Resolution

Spatial resolution: Four-level structure

- → Regional governments; cities and state
- → Local governments; cities, counties, districts
- → town, township, village
- → Grid

Emission factor: emissions/unit activity

- → Passenger ships and fishing vessels: Calculated by considering fuel consumption
- → Cargo ships: Calculated by dividing by each mode (excluding outbound ships-sailing)
- → Leisure vessels: Using data on the number of registered leisure vessels, multiply emission factor

03 Comparison of recent research cases on air pollutant monitoring

Air pollutant monitoring

Necessity

Current status of air pollutant monitoring in port area and ship sector

- Ideal process
  → establish an emission reduction policy to improve the environmental impact by utilizing the results obtained through the monitoring system.
- Insufficient basic status identification step through air pollutant monitoring
  → May decrease the accuracy, effectiveness, and efficiency of the policy



- Studies on the movement and diffusion of discharged pollutants and precursors
  → Still insufficient
  → Little meaningful studies and projects
- Leads to insufficient environmental health evaluation at the observation point
- Examine in-depth research on the movement and diffusion of emissions in the port sector of ships.

※ Research on ships and ports was insufficient
→ Investigate and analyze the literature to find out how the movement and diffusion of emissions in other fields was calculate

03 Comparison of recent research cases on air pollutant monitoring

Domestic and Foreign Research

Previous Research

Relevant Previous Studies

Title	Purpose	Note
Kim et al. (2017), PM2.5 Simulations for the Seoul Metropolitan Area: (II) Estimation of Self-Contributions and Emission-to-PM2.5 Conversion Rates for Each Source Category	Quantitative analysis of the nonlinear relationship between emission quantity and PM2.5	Examines the validity of emission quantity's rate of change when conducting the BFM through Community Multiscale Air Quality modeling system (CMAQ) model Estimates contribution and conversion rates per pollution source and emission materials in the Seoul metropolitan area
Kim et al. (2017), PM2.5 Simulations for the Seoul Metropolitan Area: (I) Contributions of Precursor Emissions in the 2013 CAPSS Emissions Inventory	Analyzes the impact of emission quantities per pollution source and material on the corresponding and neighboring areas' PM2.5 concentration in 17 local governments nationwide, and, based on the concentration contribution, estimates the concentration conversion rate per 1 ton of emission quantity per air pollutant sources for each local government	Estimates contribution rates through the CMAQ model
Bae et al. (2017), PM2.5 Simulations for the Seoul Metropolitan Area: (III) Application of the Modeled and Observed PM2.5 Ratio on the Contribution Estimation	Develops a new approach to better explain the uncertainty of the contribution rate estimated in PM2.5 modeling	Adjusts contribution rate through CCF (Contribution Correction Factor) Analyzes the effect of the CCF application on the estimated contribution and conversion rates
Bae et al. (2018), PM2.5 Simulations for the Seoul Metropolitan Area: (V) Estimation of North Korean Emission Contribution	Quantitatively analyzes how North Korea's emission quantities affect South Korean air pollution and its external influence on North Korea's air quality	Evaluates the contribution rates by conducting BFM with the CMAQ model
Kim et al. (2019) PM2.5 Simulations for the Seoul Metropolitan Area: (VI) Estimating Influence of Sectoral Emissions from Chungcheongnam-do	Analyzes the effects of sectoral emissions from Chungcheongnam-do (CCND) on PM2.5 concentrations of Seoul metropolitical areas (SMA)	Evaluates the contribution rates by conducting BFM with the CMAQ model Calculates the concentration conversion rates per emission unit for sectors with a high level of emission influence
Li & Managi (2019), Contribution of on-road transportation to PM2.5	A quantitative analysis of the association between road traffic and PM2.5 emissions. It analyzes the relationship between PM2.5 concentration and the percentage of road per km2 and the association between PM2.5 and early mortality rates	By using five different models (FEM, SPAM, SPEM, and GTWR), it identifies space-inhomogeneity from the relationship between the usage of vehicles and the urban-level PM2.5 concentration. Calculates road traffics with CO2 concentration
Askariyeh et al (2020), Near-Road Traffic-Related Air Pollution: Resuspended PM2.5 from Highways and Arterials	Based on the US EPA guidelines, it quantitatively analyzes the effects of the resuspended dust from highways and arterial roads on the traffic-related PM2.5 emission and nearby road emission concentrations	Calculates PM2.5 emission concentrations through combustion, brake wear, tire wear, or resuspended dust Adopts the AP-42 paved road resuspended dust model
Hodan & Barnard (2004), Evaluating the Contribution of PM2.5 Precursor Gases and Re-entrained Road Emissions to Mobile Source PM2.5 Particulate Matter Emissions	Studies on diverse contributions to PM2.5 in traffic	Discusses the causes of PM2.5 formation on the road, determines the contribution rate for each PM2.5 emission mechanism, and identifies the formation of precursor compounds Contribution analysis through CMB, Principal Component Analysis (PCA), and Positive Matrix Factorization (PMF)
Karl et al. (2019), Effects of ship emissions on air quality in the Baltic Sea region simulated with three different chemistry transport models	Provides evidence materials for vessel emission-related policies by the adoption of the Nitrogen emission control area (NECA)	After calculating the vessel contribution rates by utilizing CMAQ, SILAM, and EMEP/MSC-W models, it quantitatively analyzes how each model affects contribution rates.
Ginzburg et al. (2015), Monitoring study of the near-road PM2.5 concentrations in Maryland	The Maryland State Highway Administration (SHA) monitoring program evaluates effects of vehicular exhausts on PM2.5	To determine if the monitored PM2.5 concentrations are from road traffic or other sources (residential and commercial heating, air conditioning, etc.), it studies the influence of vehicle exhausts on highways on fine dust.

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Title	Purpose	Note
Karamchandani et al. (2017), Source-sector contributions to European ozone and fine PM in 2010 using AQMEII modeling data	Calculates contributions of several emission sources for O3 or PM2.5 during the summer and winter in Northern European areas	**Analyzes contributions** by adopting CAMx's contribution analysis tool, Ozone and Particulate Source Apportionment Technology(OSAT/PSAT)
Moon et al. (2021), Estimation of Contribution and Emission-to-PM2.5 Conversion Rate by Each Local Government for Policy Support	Analyzes the impact of emission quantities per pollution source and material on the corresponding and neighboring areas' PM2.5 concentration in 17 local governments nationwide, and, based on the concentration contribution, estimates the concentration conversion rate per 1 ton of emission quantity per air pollutant sources for each local government	Modeling by applying the nesting technique for 27km-9km-3km resolutions **Evaluates the contribution rates** by conducting BFM with the CMAQ model
Kim et al. (2017), Impact of Emissions from Major Point Sources in Chungcheongnam-do on Surface Fine Particulate Matter Concentration in the Surrounding Area	Contribution estimation and conversation rate calculations on the major point sources in Chungcheongnam-do, including thermal[steam] power generation	Quantitatively analyzing how the changes in **simulation input conditions affect contributions** **Evaluates the contribution rates** by conducting BFM with the CMAQ model
Kim et al. (2017), Regional contributions to particulate matter concentration in the Seoul metropolitan area, South Korea: seasonal variation and sensitivity to meteorology and emissions inventor	Estimates of the PM concentrations around the Seoul metropolitan areas of South Korea in 2014 and the sensitivities to meteorology or regional emissions (domestic and foreign) by utilizing the regional air quality modeling system	Qualitatively and quantitatively analyzes the uncertainties by metrology models in estimating emission source contribution **Evaluates the contribution rates** by conducting BFM with the CMAQ model
Kim et al. (2014), Study on the Secondary Formation Contribution of PM in Busan	Estimates the formation of the secondary air pollutant formation by utilizing physicochemical reaction equations After analyzing weather conditions, it evaluates the weather conditions' contribution to the formation of the secondary air pollutants	Reinterprets the constituting elements of PM2.5's chemical compositions **Analyzes the contribution rates** by adopting the Mass Closure Model that is used in the US administration and aerosol Interagency Monitoring of Protected Visual Environments (IMPROVE)
Ning et al. (2021), Study on the Influence of Regional Transportation on PM2.5 Based on the RAMS-CMAQ Model in Weihai, a Typical Coastal City of Northern China	Quantitatively analyzes the contributions of regional traffic on PM2.5 by adopting ISAM, an analytical tool that combines Regional Atmospheric Modeling System(RAMS) and CMAQ	**Evaluates transport contribution** for 1st and 2nd primary particles
Moon (2021), Establishment and management of a regional environment evaluation system to support environmental assessment: primary particle contribution analysis for vessels and power plants	Calculates vessels' contribution to primary particles in the nation and calculates primary particle contribution and conversion rates for each major vessel pollutant (NOx, Sox, PM2.5)	Modeling by applying the nesting technique for 27km-9km-3km resolutions **Evaluates the contribution rates** by conducting BFM with the CMAQ model
Moon (2018), Analysis System for Regional Environmental Status to Support Environmental Assessment	Summary of the atmospheric environment evaluation system and modeling scopes PM2.5 Contribution and conversion rate estimations for each municipal government.	Modeling by applying the nesting technique for 27km-9km-3km resolutions **Evaluates the contribution rates** by conducting BFM with the CMAQ model

03 Comparison of recent research cases on air pollutant monitoring

Domestic and Foreign Research

The concept and application of 'Contribution'

Contribution

To the extent that the concentration of pollutants changes in the observing point/region with the emission of a certain emission source/materials ($\mu g/m^3$)

Ex. Contribution to PM ($\mu g/m^3$)
= PM concentration in the atmosphere of the observing area(Base concentration)
– PM concentration in the atm of the observing area (Contaminant exclusion modeling)

Contribution rate

The ratio (%) of pollutant concentration, which was generated by a certain emission source or material in the observing point/area, to the pollutant concentration of the atmosphere in the observing point/area

$$Contribution\ rate(\%) = \frac{Contribution}{Pollutant\ concentration\ in\ the\ entire\ atmosphere\ including\ emission\ souces} \times 100(\%)$$

Sensitivity

The degree of changes in pollutant concentration in the atmosphere in the observing point/region when emission sources/materials reduce their volumes ($\mu g/m^3$)

※ Contribution: changes in pollutant concentrations of the emission source/material compared to the total emission amount
※ Sensitivity: Emission source/material's partial changes in concentrations compared to partial changes in emission volume
※ When the emission amount change is 100%, sensitivity values equal contribution values

Methods: Calculate Contribution

■ Receptor model

- Quantitatively analyzing the observed pollution concentration
  → Trace back emission sources
- Used without information on topography or meteorology
- Limited prediction

※ Receptor models: CMB, PMF, PA, UNMX

■ Dispersion model

- Mathematically simulating the diffusion process of the air pollutant generated in the emission source in the atmosphere
  → Assess the impact of pollution sources (Calculate, modeling)
- Needs information: weather, topography, chemical effects …
- Possible prediction
  → Can be utilized to predict long-term air pollution

※ Dispersion models: ISCST3, RADM, CMAQ, CAMx…
※ CMAQ, CAMx
→ widely used among many 3-dimensional numerical models
→ Referred to as the Chemical Transport Model, which simulates the physicochemical processes in the fixated 3-dimensional time and space grid

03 Comparison of recent research cases on air pollutant monitoring

Movement and Diffusion simulation for Pollutant

Operation of 'Chemical Transport model'

Advection, Diffusion, Chemistry

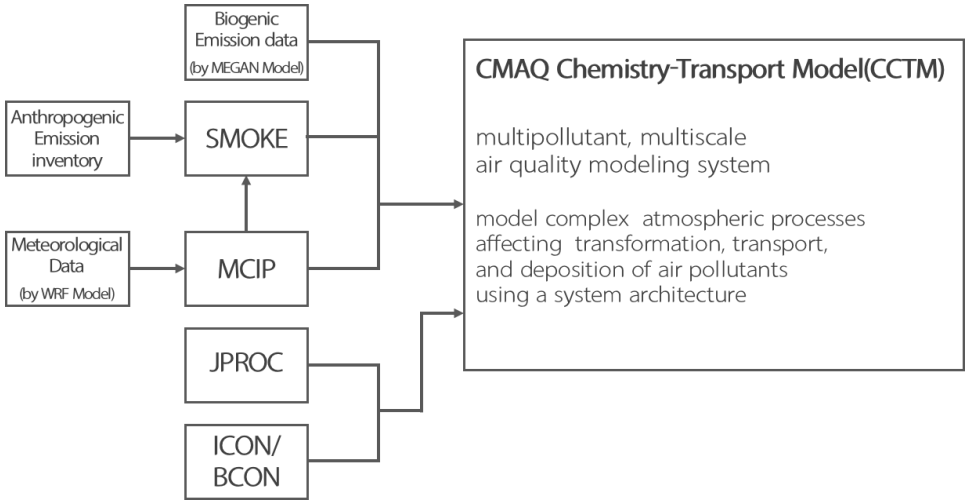
- Describes the concentration of air quality by time and space
- Including 3-dimensional meteorological model and pollutant information per each chemical type into the Atmospheric Chemical Transport Model

※ Predicts the changing values of air pollution concentrations for a particular point/region according to a certain emission source or emission materials

→ Provides basic information **to choose and adopt optimal technologies and policy options** to understand and address the problems, including air pollution and the resulting public hazard to local society

※ Chemical Transport Models: CMAQ, CAMx, REMSAD, UAN-Aero…

Example: CMAQ model



| Explanation of the CMAQ Model|

- Describes the average chemical concentrations for each grid over time

※ Calculates the physicochemical process of pollutants for each chemical pollutants in the 3-dimensional grid
※ Physicochemical process: emission, diffusion, chemical reaction, and removal process

- The accuracy of input data, including meteorological and emission data
  → determinants of confidence on output values

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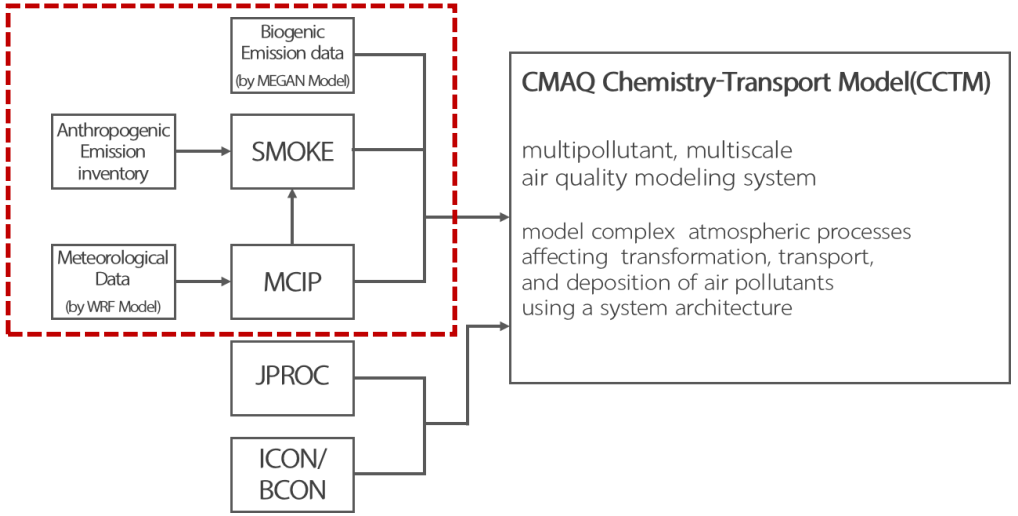

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Operation of 'Chemical Transport model'

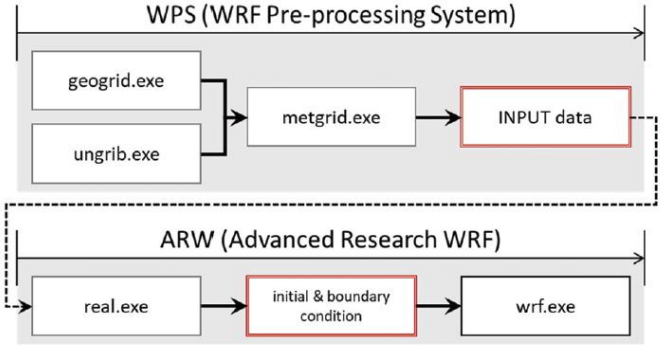
01 Meteorological Model

- Type of numerical model
- Predicts the meteorological data through simulation

※ Meteorological models: MM5, WRF, etc.
※ Input data: meteorological data, geographical data
→ Meteorological initial input data: NCEP-FNL
→ Geographical data: DEM(Digital Elevation Model, LandCoverMap
※ Output values: Meteorological data by time/grid (temperature, wind speed, wind direction…)

- Components of Meteorological Model: WPS, ARW

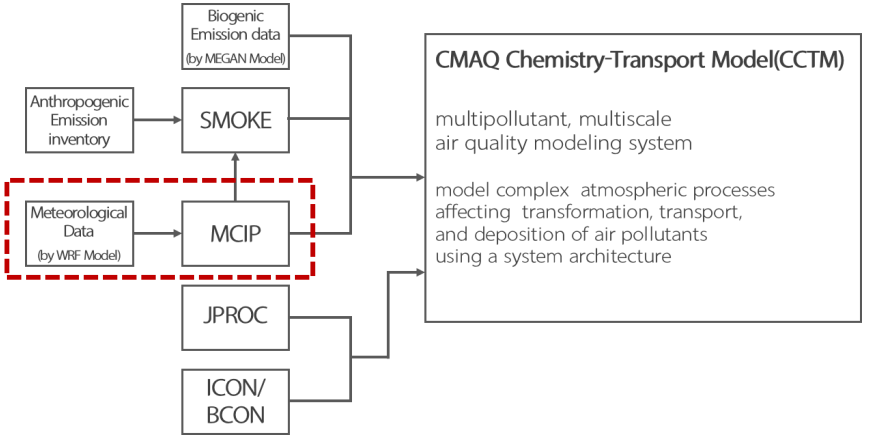
→ WPS: creates input data by setting up the target areas and combining its topography, weather and other information
→ ARW: creates the initial conditions and boundary conditions by utilizing the input data creased by WPS



| Explanation of the WRF Model|

Choi et al.(2019)

- Created meteorological data
→ transformed through the MICP model
→ transmitted to CMAQ



| Explanation of the CMAQ Model|

03 Comparison of recent research cases on air pollutant monitoring

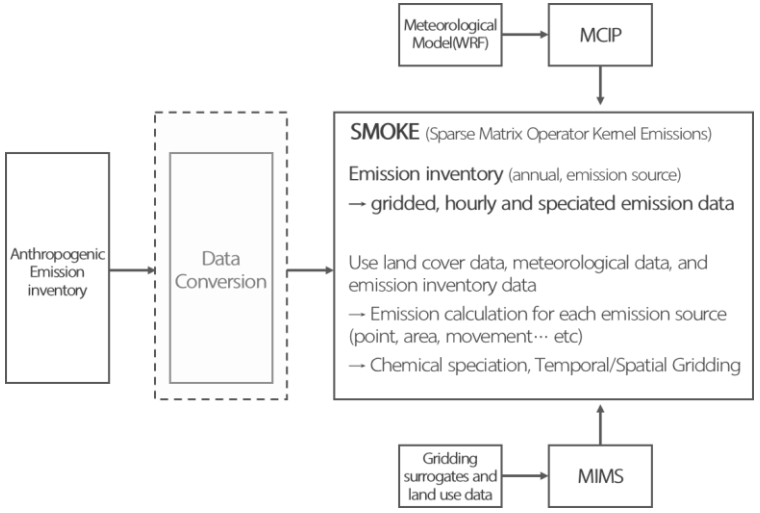
Movement and Diffusion simulation for Pollutant

Operation of 'Chemical Transport model'

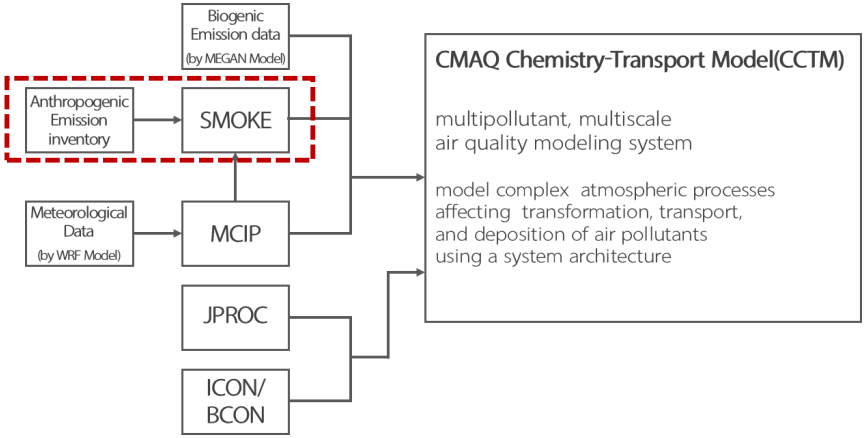
02 Emission Model

- Converts the emission inventory into input data for the air quality model

※ Emission Models: SMOKE, ECIP, EPS, etc…
※ Input values: Emission inventory, Land cover data, Meteorological data…
→ Meteorological initial input data: NCEP-FNL
→ Geographical data: DEM(Digital Elevation Model, LandCoverMap
※ Output values: emission quantities by grids, times, and chemical types



| Explanation of the SMOKE Model|



| Explanation of the CMAQ Model|

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Movement and Diffusion simulation for Pollutant

Operation of 'Chemical Transport model'

02 Emission Model

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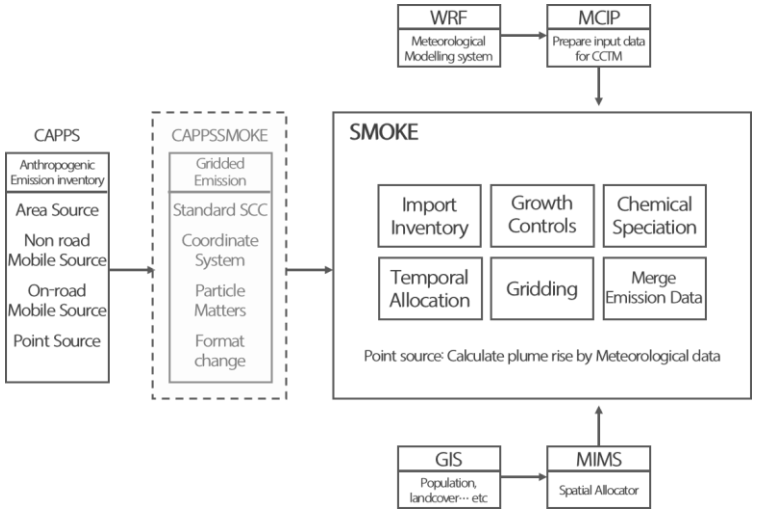
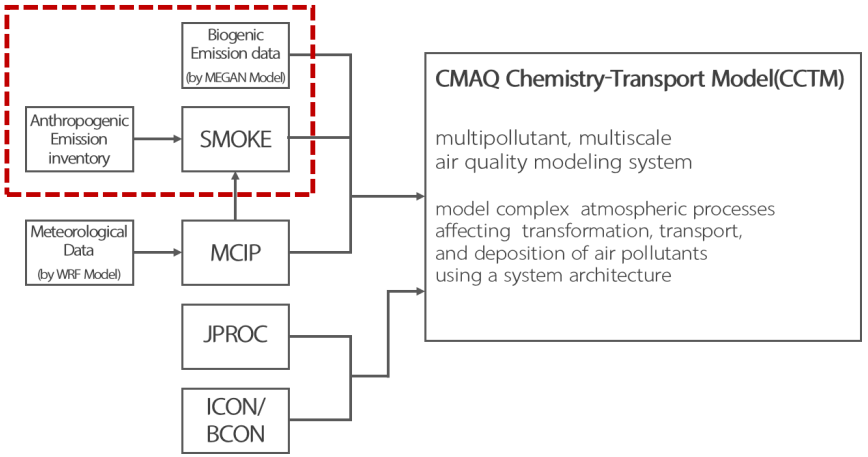


| Explanation of the SMOKE Model|

- Emission data

※ Anthropogenic Emission data
Emission Inventory → Convert by SMOKE
※ Biogenic Emission data
Simulate by MEGAN Model



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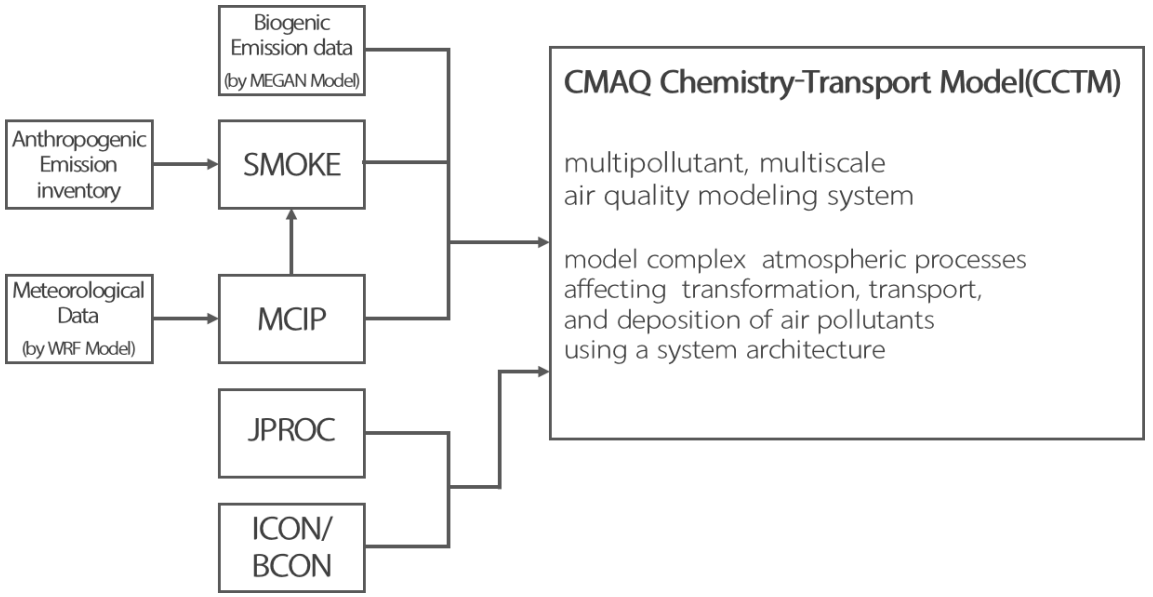
Operation of 'Chemical Transport model'

03 Chemical Transport Model

- Describes the concentration of air quality by time and space
- Including 3-dimensional meteorological model and pollutant information per each chemical type into the Atmospheric Chemical Transport Model



| Explanation of the CMAQ Model|

03 Comparison of recent research cases on air pollutant monitoring

Movement and Diffusion simulation for Pollutant

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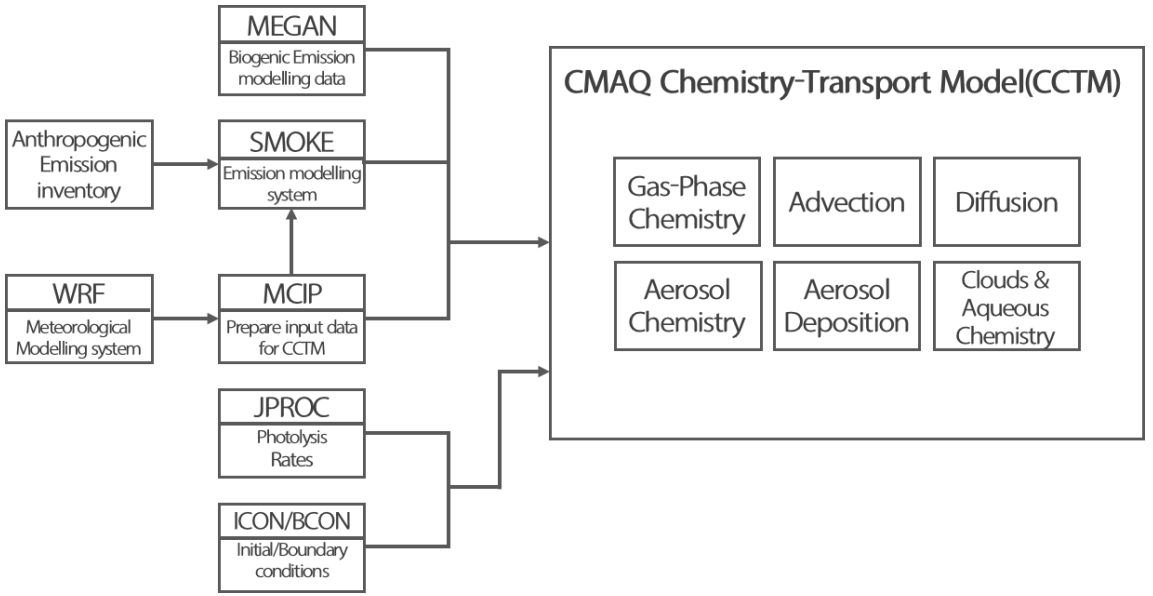

| Explanation of the CMAQ Model|

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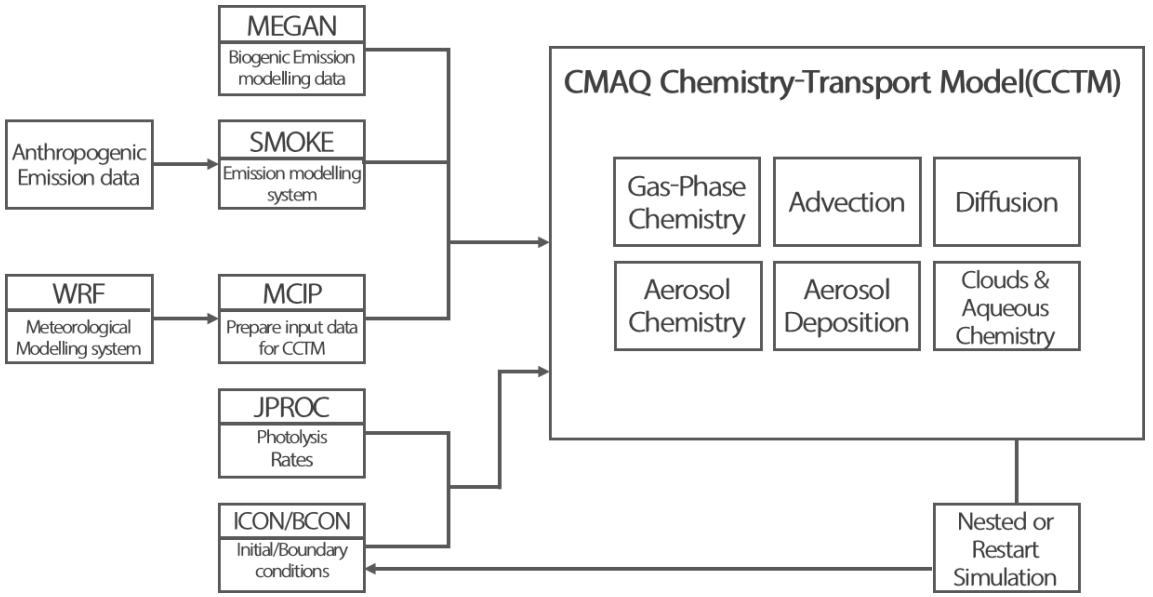

| Explanation of the CMAQ Model|

- BCON: As the data on the most external parts of the target area, they separately provided by utilizing general atmospheric chemical components.
- ICON: When simulating atmospheric chemistry, the first time period does not have reference data on emission concentrations. Thus, there needs to be additional concentration data.
- JPROC: Photolysis, provides the energy required for many chemical reactions to occur in the atmosphere
- Gas-phase Chemistry: Chemical reactions or reaction velocity on the gas
- Aerosol Microphysics: particles' introduction to and removal from the atmosphere
- Cloud Aqueous Process: pollutant generation and elimination by clouds

04 Findings

Comparison of research cases according to keywords

Comparison of emission data among input data

01 Used recent data?

- Used emission data from 4 years ago, at most 8 years ago

Thesis	Time of research	Data used		Characteristics
		Agriculture	Nature	
Kim et al(2017)	2014	Foreign: 2010 CREATE Domestic: CAPSS 2013	MEGAN ver.2.1	Using SMOKE ver.3.1, space-time allocation for each SCC ※ SCC: Source category
Kim et al(2017)	**2014**	Foreign: **2010 CREATE** Domestic: CAPSS 2013	MEGAN ver.2.1	Using SMOKE ver.3.1, space-time allocation for each SCC
Bae et al(2017)	2014	Foreign: 2010 CREATE Domestic: CAPSS 2013	MEGAN ver.2.1	Using SMOKE ver.3.1, space-time allocation for each SCC
Bae et al(2018)	2016	Foreign: 2015 CREATE Domestic: CAPSS 2013	MEGAN ver.2.1	Using SMOKE ver.3.1, space-time allocation for each SCC
Kim et al(2019)	2015	Foreign: 2015 CREATE Domestic: CAPSS 2013	MEGAN ver.2.04	Using SMOKE ver.3.1, space-time allocation for each SCC
Prakash Karamchandani et al.(2017)	2010	TNO-MACC II	MEGAN	Using SMOKE ver.3.1, space-time allocation for each SCC
Moon et al(2021)	2015	Foreign: 2015 CREATE Domestic: CAPSS 2013	MEGAN	Using SMOKE ver.3.1, space-time allocation for each SCC
Kim et al(2017)	**2014**	Foreign: **INTEX-B 2006**, MICS-Asia 2010 Domestic: INTEX-B 2006, **CAPSS 2007, CAPPS 2010**	MEGAN	Using SMOKE ver.3.1, space-time allocation for each SCC
M. Karl et al(2019)	2012	EMEP, ECLIPS, 2011 STEAM		Real world stack information obtained from EMEP is calculated through SMOKE-EU. Port emissions are calculated through the STEAM model.

04 Findings

Comparison of research cases according to keywords

Comparison of emission data among input data

02 Spatial resolution of emission data

- Not enough density, lower resolution than the simulated resolution

Thesis	Simulation area	Horizontal resolution when simulated	Data used		Characteristics
			Model used	Space-time resolution	
Kim et al(2017)	Northeast Asia South Korea	27-km 9-km	Foreign: 2010 CREATE	Resolution for one year, regional	Air quality simulation for metropolitan area
			Domestic: CAPSS 2013	1 month or 1 year, regional	
Kim et al(2017)	Northeast Asia South Korea	27-km 9-km	Foreign: 2010 CREATE	Resolution for one year, regional	Air quality simulation for metropolitan area
			Domestic: CAPSS 2013	1 month or 1 year, regional	
Bae et al(2017)	Northeast Asia South Korea	27-km 9-km	Foreign: 2010 CREATE	Resolution for one year, regional	Air quality simulation for metropolitan area
			Domestic: CAPSS 2013	1 month or 1 year, regional	
Bae et al(2018)	Northeast Asia South and East Korea	27-km 9-km	Foreign: 2015 CREATE	Resolution for one year, regional	Estimating the impact of North Korean emissions
			Domestic: CAPSS 2013	1 month or 1 year, regional	
Kim et al(2019)	South Korea	**9-km**	Foreign: 2015 CREATE	Resolution for one year, **regional**	A study on the effect on concentration in the metropolitan area in Chungcheongnam-do
			Domestic: CAPSS 2013	1 month or 1 year, **regional**	
Prakash Karamchandani et al.(2017)	Regions covering parts of Europe and Africa	23-km	TNO-MACC II	1 year, ~7km*7km,	Investigation of the impact of the anthropogenic source sector on the whole of Europe
Moon et al(2021)	Northeast Asia South and East Korea	27-km 9-km **3-km**	Foreign: 2015 CREATE	Resolution for one year**, regional**	3km resolution applied for analysis of contribution by local government
			Domestic: CAPSS 2013	1 month or 1 year**, regional**	
Kim et al(2017)	Northeast Asia South Korea SMA	27-km	Foreign: INTEX-B 2006, MICS-Asia 2010	1 month, 30°*30° resolution 1 year, 2.5°*2° or 2.8°*2.8° degree	Considering the impact of overseas and domestic emissions on the metropolitan area
			Domestic: INTEX-B 2006, CAPSS 2007, CAPPS 2010	1 month, 30°*30° resolution 1 month or 1 year, regional	

04 Findings

Comparison of research cases according to keywords

Comparison of emission data among input data

03 Spatial resolution in simulation

- Used different resolutions for different attribution analysis purposes

Thesis	Simulation area	Horizontal resolution when simulated	Data used		Characteristics
			Model used	Space-time resolution	
Kim et al(2017)	Northeast Asia South Korea	27-km 9-km	Foreign: 2010 CREATE	Resolution for one year, regional	Air quality simulation for metropolitan area
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04 Findings

Comparison of research cases according to keywords

Comparison of models simulated movement and diffusion by emission

01 Use different calculation method

- Non-liner emission effect → Can make different simulation result by using different calculation method

Thesis	MODEL	Detailed Algorithm in the Simulation Model		How Contribution is Calculated
		Chemical mechanism	Aerosol module	
Kim et al(2017)	CMAQver4.7.1	SPARC99	AERO5	**BFM (Brute Force Method) 50% (some 20%, 80% Emission perturbation)**
Kim et al(2017)	CMAQver4.7.1	SPARC99	AERO5	BFM (Brute Force Method) 100%
Bae et al(2017)	CMAQver4.7.1	SPARC99	AERO5	BFM (Brute Force Method) 50%
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Kim et al(2019)	CMAQver4.7.1	SPARC99	AERO5	BFM (Brute Force Method) 50%
Prakash Karamchandani et al.(2017)	CAMx ver6.1	Carbon Bond2005(CB05)	Coarse-fine (CF)	**OSAT, PSAT (SOA is not calculated from PSAT)**
Moon et al(2021)	CMAQver4.7.1	SPARC99	AERO5	BFM (Brute Force Method) 100%
Kim et al(2017)	CAMQ ver 4.7.1	SPARC99	AERO5	BFM (Brute Force Method) 100%
M. Karl et al(2019)	CMAQ v5.0.1	CB05	AERO5	Ship influence on ambient NO2: Aulinger et al. (2016) performed both using all available emissions including the ship emission inventory and using land-based emissions exclusively (1) the concentrations increased (2) the temporal correlation improved when shipping emissions were included in simulation
	SILAM	CB04 reaction rates updated according to the recommendations of the International Union of Pure and Applied Chemistry (IUPAC) and the NASA Jet Propulsion Laboratory (JPL)	DMAT scheme volatility basis set (VBS) Shrivastava et al. (2011) Prank et al. (2018)	
	EMEP/MSC-W	EmChem09	VBS	

04 Findings

Comparison of research cases according to keywords

Comparison of models simulated movement and diffusion by emission

02 Use different algorithm in the simulation model

- Use different chemical species classification or chemical reaction → the simulation result may be different.

Thesis	MODEL	Detailed Algorithm in the Simulation Model		How Contribution is Calculated
		Chemical mechanism	Aerosol module	
Kim et al(2017)	CMAQver4.7.1	SPARC99	AERO5	BFM (Brute Force Method) 50% (some 20%, 80% Emission perturbation)
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	EMEP/MSC-W	EmChem09	VBS	

04 Findings

Problem & Solution

Time difference between input data → Lowered reliability of simulation results

Problem

- $PM_{2.5}$ generation in Korea
  - → Movement and diffusion of pollutants emitted from **domestic sources**
  - → **Inflow of foreign pollutants** into the country
- Reliability of the movement and diffusion simulation
  - → Depend on the accuracy of the emission and meteorological data
- Time difference between input data
  - → **affect the reliability, cause serious errors**

Overseas emission data: use previous data

- Lack of recent measured foreign emission data
  - → Estimation of current emission trends using past emission data
  - ※ REAS, INTEX, and EDGAR are based on **before 2006**
  - → **do not reflect recent changes** in social and economic activity in Asia and changes in the emission characteristics of air pollutants.
- CREATE data
  - → Estimated by reflecting the growth coefficient using specific factors for estimating the current emissions in the activity data surveyed in the past, not the annual calculated emissions
  - → May be different from the actual value.

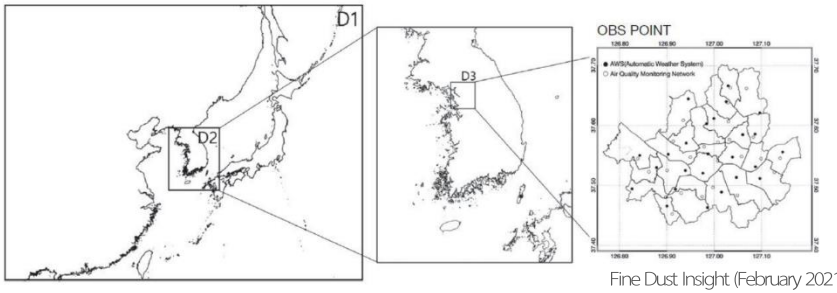
Solution

- Use the measured emission data rather than using the estimated value from the past emission data when calculating foreign emissions
- Necessary to establish a DB or platform for sharing emission data that can be used jointly in Asia, East Asia, or Asian regions

Influence of Foreign Emission Data - Establishment of Boundary Conditions

■ Nesting Grid

- The values calculated in the large area are used as boundary conditions for the small area.



Fine Dust Insight (February 2021)

| Simulation Area of Air Quality Model in Numerical Forecast Modeling System for National Air Quality Forecast|

04 Findings

Similar Case

European Example: TNO-MACCII Emissions Inventory

01 AQMEII

- Air Quality Modelling International Initiative
- To improve uncertainty in ozone and $PM_{2.5}$ model projections, North America (NA) and the European Union (EU) promote the development of air quality models and lay a common basis for the evaluation of air quality models
- Modeling groups in Europe and North America run regional air quality models to reanalyze MACC

02 MACC

- Annual emissions and time functions for the Monitoring atmospheric composition & climate (MACC) project
- For Europe and North America
- Developed by The Netherlands Organization for Applied Scientific Research(TNO) Spatial resolution: 0.125 deg longitude(~9km at 47deg lat), 0.0625deg latitude(~7deg lat)
- Time resolution: Seasonal, weekly and diurnal variation
- Emission Inventory: PM_{10}, $PM_{2.5}$, CH_4, CO, NH_3, NMVOC, NO_x and SO_2 for SNAP classification

03 MACC-II

- Based on official national emissions reported by European countries to the EU, UNFCC, etc…

※ Convention for Long-Range Transboundary Air Pollution (CLRTAP) requires countries to report their emissions

※ Fifty-one countries in Europe and North America, including the EU as a whole, have to annually submit their emissions of air pollutants for the latest year and all historic years to EMEP

※ The data is completed with alternative emission estimates as needed and, if specific national methodologies are not available, the base guidelines set out in the EMEP/EEA Air Pollutant Emission Inventory Guidebook are used.

- Extended time to 2009, use of latest reported data (including updates and corrections made through early 2012), distribution updates

| Explanation of the SNAP source categories |

SNAP	Sector name
1	Energy industries
2	Non-industrial combustion
34	Industry (combustion + processes)
5	Extraction and distribution of fossil fuels
6	Product use
7	Road transport
8	Non-road transport and other mobile sources
9	Waste treatment
10	Agriculture

04 Findings

Problem & Solution

Low resolution of domestic emission data → Lowered reliability of simulation results

Problem

- National air pollutant emissions

→ Announced annually by the Clean Air Policy Support System (CAPPS) targeting nine air pollutants

- Emission inventory

→ Distributed over densely divided space-time intervals through the empirical algorithm of the SMOKE model

Division and distribution through SMOKE

- Emissions

→ Calculated separately for each emission source such as point, surface, movement, and natural pollution source

→ Have the flowing time resolution

※ Time resolution: Monthly resolution

※ if monthly emissions cannot be calculated, calculate them annually and then allocate them at a monthly rate

※ Spatial resolution: With a four-level structure

※ the amount of space is allocated when the emission is calculated at the upper spatial resolution

→ The emission data distributed through the SMOKE model are essential input data to understand the concentration change in the atmosphere caused by movement and diffusion.

→ Since this is data estimated by a certain algorithm, not actual observation data at each point in time, errors and distortions may occur when simulating the effect of specific demand.

Solution

- Calculate domestic emission data in a more dense space-time grid unit.

→ Applying a bottom-up model that reflects the activities of individual emission sources

- High-resolution emission data is used as input to the SMOKE model

→ Relatively more accurate results are expected than when low-resolution emission data is applied to the SMOKE model.

- Improve accuracy when simulating movement and diffusion caused by emission at a specific point in time

04 Findings

Similar Case with lesson

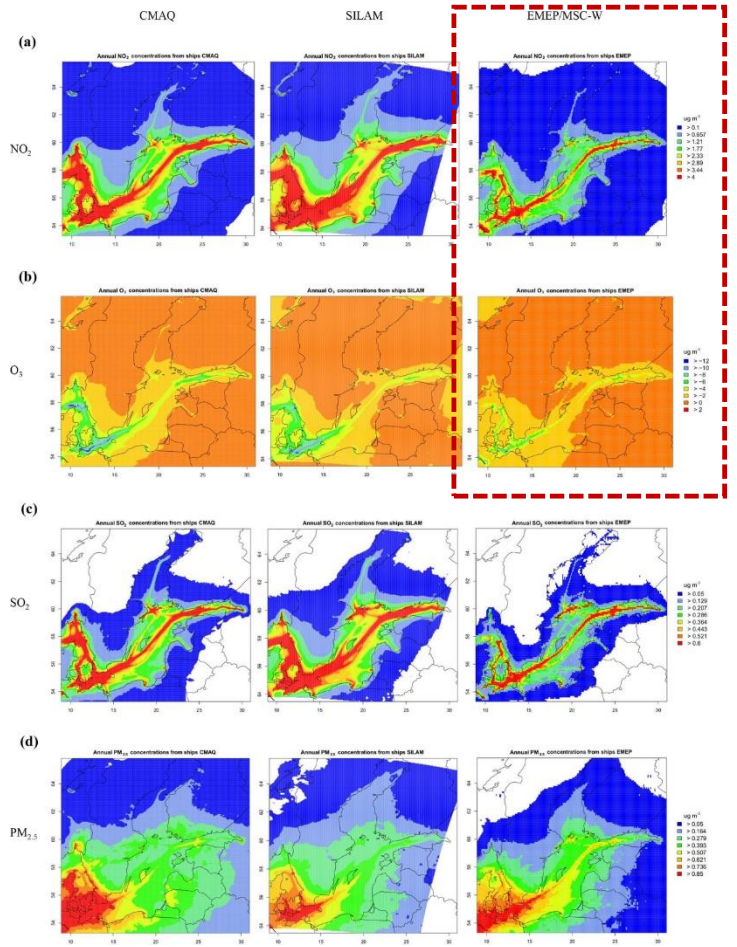
Karl, Matthias, et al. (2019) Effects of ship emissions on air quality in the Baltic Sea region simulated with three different chemistry transport models

- Simulation of movement and diffusion of ship emissions using different models in the Baltic Sea region
  → Each model has a different spatial resolution, and the simulated data is compared with the observed data
  → EMEP/MSC-W model with a horizontal resolution of 11X11km^2 on the regional scale used monthly averaged gridded ship emissions, while the other two models used hourly emissions
- Significant differences in the calculated ship contributions to the levels of air pollutants among the three models
- In EMEP/MSC-W, ozone depletion by **NO emissions from shipping is weaker than in the other two models**

| Description of the model set-up of the three CTM system |

Model parameter	CMAQ	SILAM	EMEP/MSC-W
Horizontal grid resolution of the inner nest	4 × 4 km^2	4 × 4 km^2	0.1° × 0.1°
Nesting	D1: 64 km D2: 16 km D3: 4 km	D1: ~ 70 km D2: ~ 18 km D3: 4 km	D1: 0.1°
Meteorological driver	COSMO-CLM	WRF	IFS-ECMWF, Cy40r1
Chemical boundary and initial conditions	FMI APTA global reanal-ysis	FMI APTA global reanal-ysis	Climatology for ozone
Land-based emissions	SMOKE-EU	SMOKE-EU	ECLIPSE
Ship emissions	STEAM 2 × 2 km^2	STEAM 2 × 2 km^2	STEAM 0.1° × 0.1°
Ship emission time variability	hourly	hourly	monthly

※ CTM: Chemistry Transport Model



| Comparison of the spatial distribution of annual mean ship-related concentrations (absolute ship contributions in μg m-3) |

04 Findings

Problem & Solution

Show differences results due to differences in algorithms for each program

Problem

- Different algorithm in the program used for movement and diffusion simulation
- CMAQ program

→ most domestic studies use to simulate the movement and diffusion of emitted substances.

- Use different algorithm depending on the CTM

→ May ignore or exaggerate some results

Options	Model	
	CMAQ	CAMx
Dry Deposition	M3DRY	Zhang, Wesely
Organic Chemistry	SORGAM	SOP
Grid nesting	One-way	Two-way
Chemical mechanism	SPARC99, CAPRC07, CB05	SPARC99, CAPRC07, CB05, CB6
Chemical solver	EBI	EBI, RADM-AQ, ISORR OPIA
Aerosol module	AERO5	CF, CMU 2-mode Model
Vertical advection	WRF	Implicit
Horizontal advection	YAMO	PPM
Vertical diffusion	ACM2	Eddy
Cloud scheme	RADM	RADM
Contribution analysis tool	OTPM, PPTM	PSAT, OSAT

Solution

- Use multiple program → comparison and correction the results
- Compare and correct the results after using different chemical mechanisms or different organic chemical mechanisms within the same program

Difference by algorithm applied in chemical transport modeling

■ Chemical Mechanism

- SAPRC Chemical Mechanism

→ A lumped molecule method that divides VOCs into similar substances for organic compounds

- CB Chemical Mechanism

→ A lumped structure method that classifies it according to the type of carbon bond

※ In addition to the organic compound classification method, there are differences in the application of chemical reaction formulas, reactants, parameterization and approximation methods.

04 Findings

Similar Case with lesson

Karl, Matthias, et al. (2019) Effects of ship emissions on air quality in the Baltic Sea region simulated with three different chemistry transport models

- Simulation of movement and diffusion of ship emissions using different models in the Baltic Sea region
  - → Different spatial resolution
  - → Compare simulated data with the observed data
- Differences in ship-related $PM_{2.5}$ among the models
  - → Mainly attributed to differences in the schemes for inorganic aerosol formation
  - → Explained by differences in the meteorological conditions, the treatment of atmospheric transport and the wet-scavenging parameterizations in the models

| Description of the model set-up of the three CTM system|

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Ship emission time variability	hourly	hourly	monthly

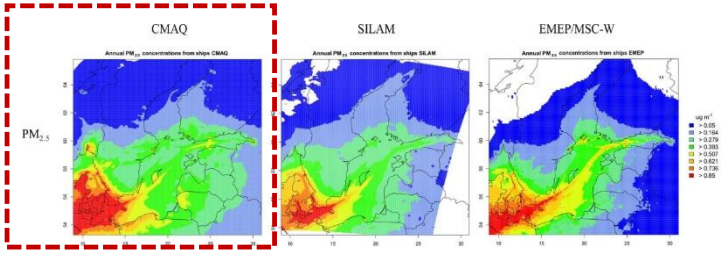
※ CTM: Chemistry Transport Model

| Spatial averages of the annual mean concentrations of NO_2, O_3, SO_2, $PM_{2.5}$ and EC in μg m^{-3}|

CTM	NO_2	O_3	SO_2	$PM_{2.5}$	EC
CMAQ	3.49	54.1	1.11	4.84	0.16
SILAM	4.82	56.7	1.65	5.94	0.15
EMEP/MSC-W	3.00	66.6	0.56	4.01	0.13

| Relative ship contribution to the spatial average of annual mean concentrations of NO_2, O_3, SO_2, $PM_{2.5}$ and EC in μg m^{-3}|

CTM	NO_2	O_3	SO_2	$PM_{2.5}$	EC
CMAQ	28.3 (20.3)	−0.4 (0.4)	14.5 (10.1)	6.5 (5.7)	7.3 (5.0)
SILAM	25.6 (17.6)	−0.4 (0.1)	11.8 (8.7)	4.1 (3.1)	5.4 (4.1)
EMEP/MSC-W	21.8 (16.1)	−0.1 (0.4)	19.1 (14.1)	5.7 (4.6)	5.3 (3.6)



| Comparison of the spatial distribution of annual mean ship-related concentrations (absolute ship contributions in μg m^{-3}) |

04 Findings

Problem & Solution

Non-combustible occurrences are not included in the construction of national statistics for ports

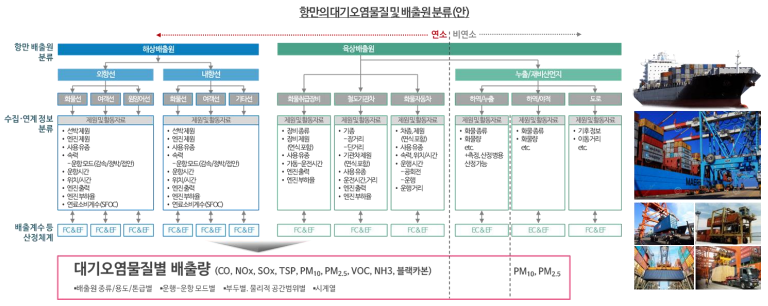
Problem

- Port emission statistics

→ Not officially included in the current National Air Pollution Emission Statistics by CAPSS

→ Non-combustible emissions: not taken into account in port emissions

Port Emissions



| Classification of port emission sources |

- Non-combustible emissions

→ account for a certain amount of port emission sources.

- If **only combustible emissions** are used as emission data from ports, monitoring data calculated by that emissions data is only a result of combustible emissions

→ Not all monitoring data calculated from emissions from ports

- Non-combustible emissions may differ from combustible emissions in the form and nature of their emissions and movement and diffusion, and impacts.

Solution

- Calculating separately by including the port sector in national statistics

→ Necessary to include and apply combustible sources & non-combustible sources.

- Develop and apply a separate methodology for identifying non-combustible emissions and generation, movement and diffusion, and impacts of ports.

Non-combustible emissions by port (estimated)

Unloading/leakage

- VOCs leakage in the form of evaporative emissions during the loading and unloading of oil/petrochemical products

Ex. Yeosu Gwangyang and Ulsan Ports with a high volume of oil and petrochemical products

Unloading/ open freight storage

- Dust emission generated during loading and unloading of bulk cargo

Ex. Incheon Port with high volume of bulk cargo

Road

- PM_{10} and $PM_{2.5}$ emissions from cargo handling equipment in the port, tire wear of automobiles, and road re-scattering dust

04 Findings

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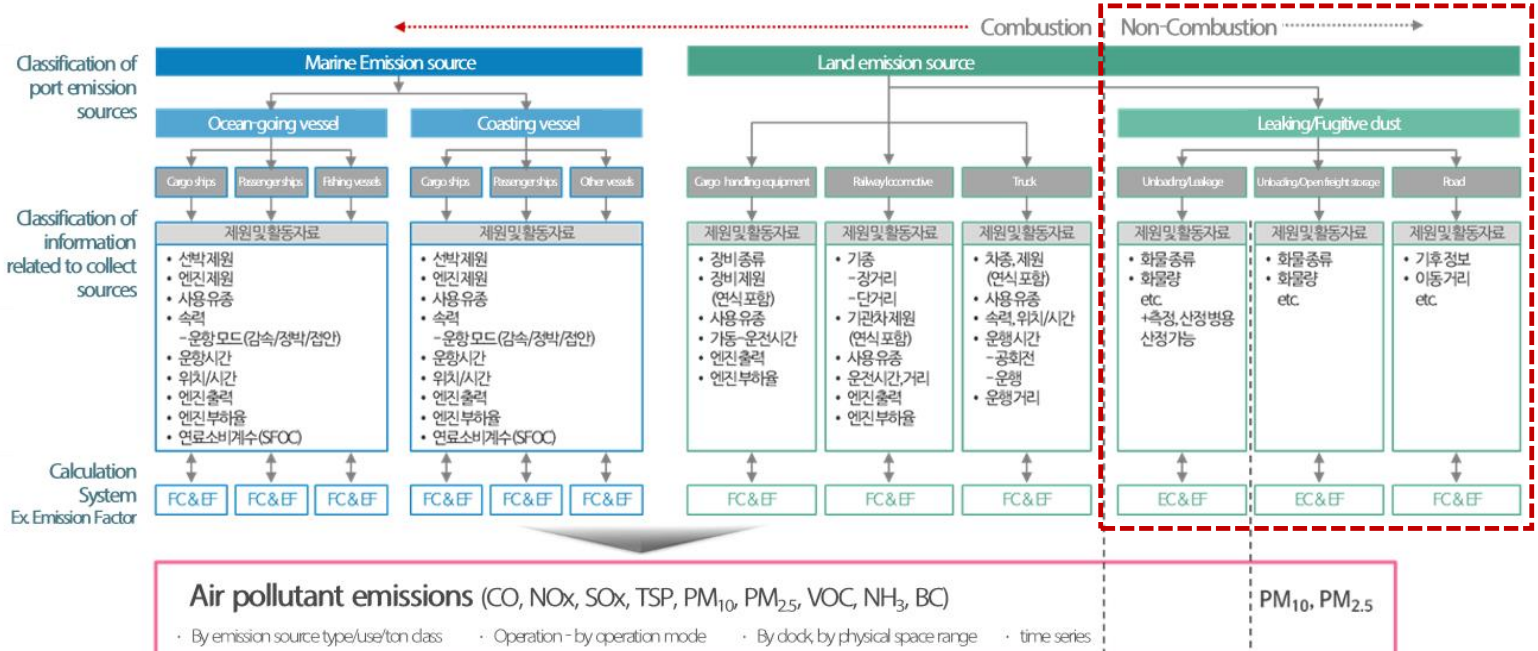
Classification of port emission sources



| Classification of port emission sources |



04 Findings

Problem & Solution

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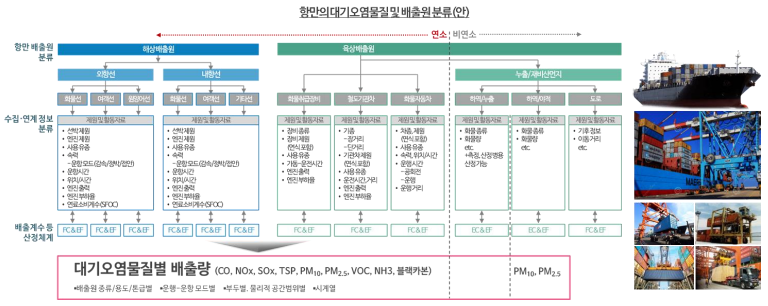

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- Non-combustible emissions

→ account for a certain amount of port emission sources.

- If **only combustible emissions** are used as emission data from ports, monitoring data calculated by that emissions data is only a result of combustible emissions

→ Not all monitoring data calculated from emissions from ports

- Non-combustible emissions may differ from combustible emissions in the form and nature of their emissions and movement and diffusion, and impacts.

Solution

- Calculating separately by including the port sector in national statistics

→ Necessary to include and apply combustible sources & non-combustible sources

- Develop and apply a separate methodology for identifying non-combustible emissions and generation, movement and diffusion, and impacts of ports.

Non-combustible emissions by port (estimated)

Unloading/leakage

- VOCs leakage in the form of evaporative emissions during the loading and unloading of oil/petrochemical products

Ex. Yeosu Gwangyang and Ulsan Ports with a high volume of oil and petrochemical products

Unloading/ open freight storage

- Dust emission generated during loading and unloading of bulk cargo

Ex. Incheon Port with high volume of bulk cargo

Road

- PM_{10} and $PM_{2.5}$ emissions from cargo handling equipment in the port, tire wear of automobiles, and road re-scattering dust

Thank you

Kim, Seo Young
Korea Maritime Institute(KMI)