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International Emission Inventory Conference
28th Sept. 2023

Validation study on the reliability of ship air emission estimation algorithm using AIS activity data

Yongchan Lee, Jiye Yoo, Heekwan Lee
Department of Environmental Engineering

Incheon National University

South Korea



인천대학교
INCHEON NATIONAL UNIVERSITY

Contents

I. INTRODUCTION

II. METHODOLOGY

III. RESULT AND DISCUSSION

IV. CONCLUSION

I. INTRODUCTION

1.1 Background



Increased demand for enhanced management of ship air pollutants in port

- Particulate matter is classified as highly hazardous substance by International Agency for Research on Cancer due to the mutagenic and carcinogenic agent
- Portion of air pollution from vessel in the Port-city occupies the largest

- International Maritime Organization (IMO) has addressed beneficial implementation such as sulfur limit of vessel fuel oil, GHGs reduction and determination of emission control area (ECA)

Five beneficial changes from IMO's Sulphur Limit for ships' fuel oil

Sulphur 2020

- Cleaner air**
77% drop in overall sulphur oxide (SOx) emissions from ships – annual reduction of approximately 8.5 million metric tonnes of SOx
- Positive impacts on human health**
Premature deaths, cardiovascular, respiratory and pulmonary diseases will all be reduced
- Higher quality fuels**
The majority of ships will switch to higher quality, low sulphur fuel oil to meet the limit.
- Ship operators, owners + refineries have adapted**
Guidance issued by IMO and other stakeholders to enhance preparedness ahead of the entry into force of Sulphur 2020
- Changes for enforcement authorities**
Flag and port State control will be making sure ships are compliant.

IMO 2020
Taking bold action to clean up shipping emissions by reducing the sulphur content in ships' fuel oil

HOW?
SULPHUR content reduced from 3.50% to 0.50% significantly less sulphur permitted in ships' fuel oil

WHY?
IMO 2020 will reduce SOx emissions from ships – annual reduction of approximately 8.5 million metric tonnes of SOx

AIR POLLUTION & HEALTH

- Premature deaths avoided
- Significant reduction in shipping's negative effect on human health through air pollution

Reduction in:

- Premature deaths
- Cardiovascular disease
- Pulmonary disease

Causing:

- Less sulphur emissions
- Less particulate emissions
- Less harmful to crops, forests and aquatic resources
- Less harmful to marine infrastructure

WHERE?

- Health benefits are globally
- Stronpest in coastal communities
- Major impact in vulnerable areas

#IMOSulphurLimit #BreatheLife #BestAirPollution

Korea : 『SPECIAL ACTION THE IMPROVEMENT OF AIR QUALITY IN PORT AREAS』 after 2020.01.01

- *Special Action The Improvement of Air Quality in Port Areas* entered into force on 1 January 2020 as a part of an ongoing national program to reduce air pollution from shipping and port activities. The act introduces a series of measures, some of which will have direct impact on ships' operational practices, and we advise ship operators and masters

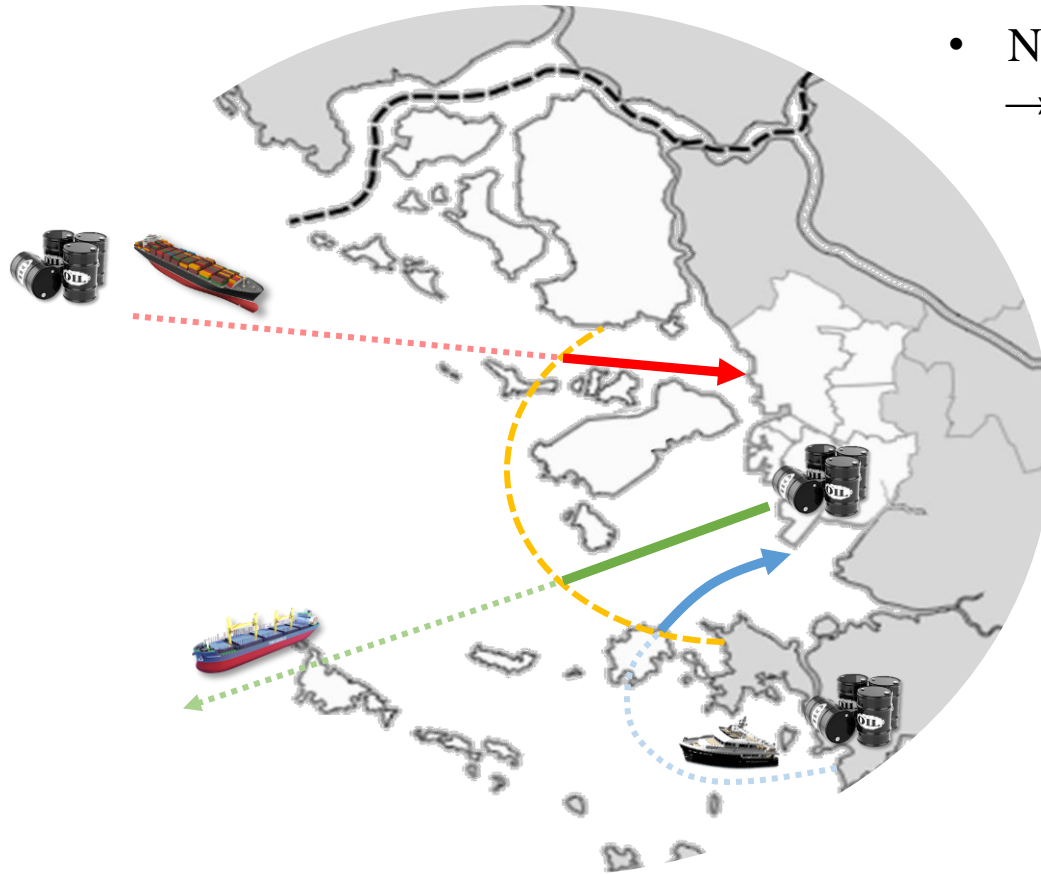
정박 중인 선박에 육상전력을 공급하는 시스템

신박은 정박 중에도 필수 전기설비 사용을 위해 자체 유류 발전기를 가동 >> 오염물질 배출

대기질관리구역
배출규제지역
지속개선지역

I. INTRODUCTION

1.1 Background



- National guideline - Fuel based (Tier 2) Estimation
→ Overseas-bunkered foreign vessels / other-port-bunkered domestic vessels (sailing overseas/other ports) are excluded to estimate ship emissions

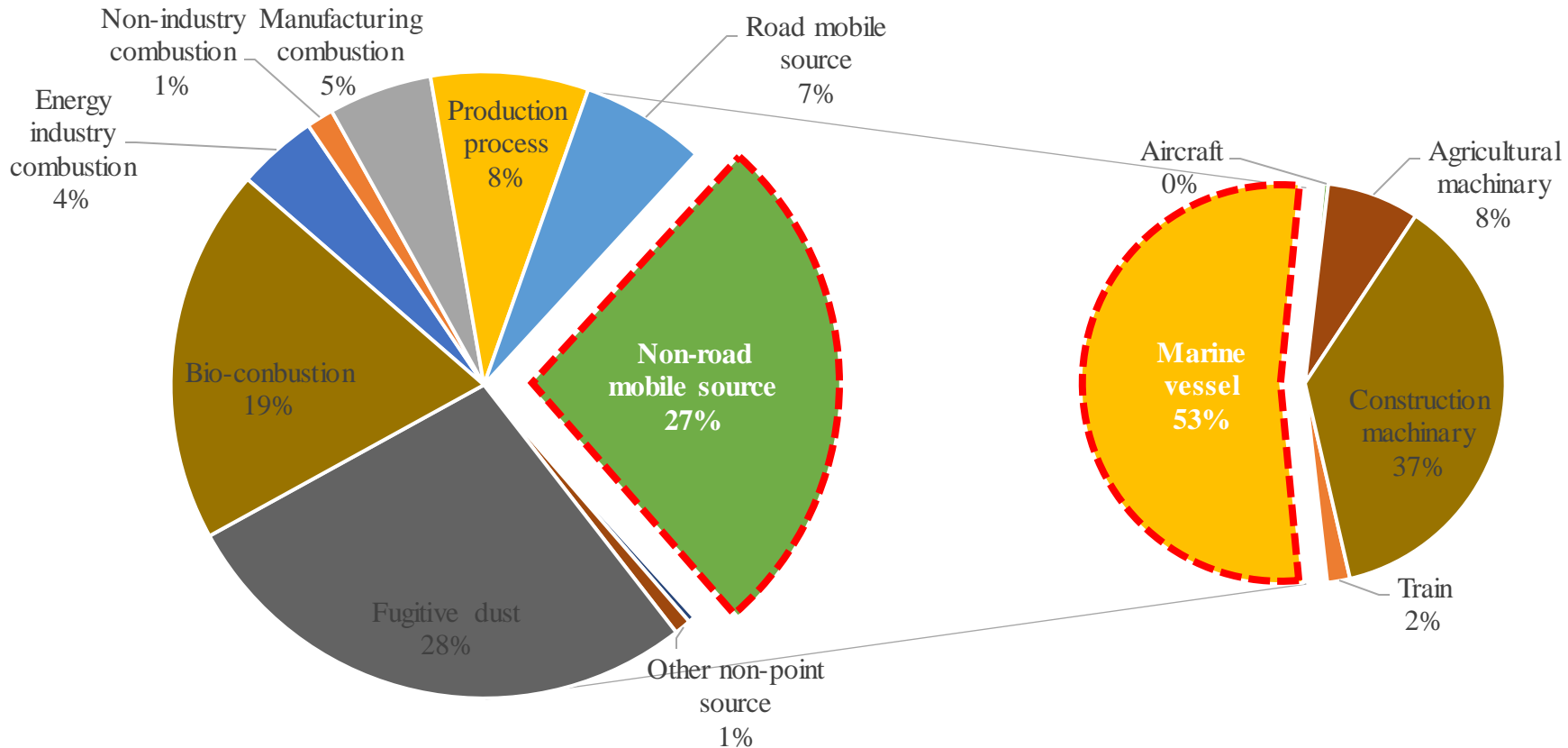
	Inner harbor limit	Outer harbor limit
Domestic vessel	Counted !!	
Foreign vessel		Unknown !!

II. METHODOLOGY

2.1 Characteristics of study area



(Unit: kg/year)



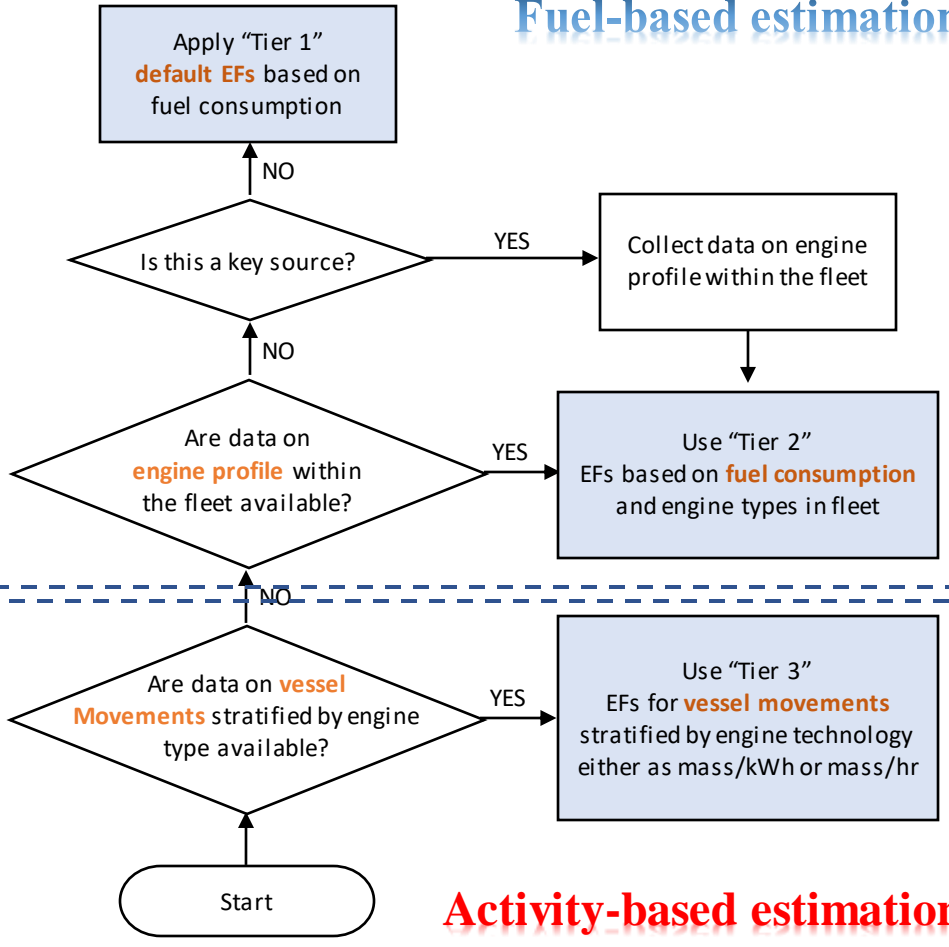
2020 PM_{2.5} Emission Inventory from
Clean Air Policy Support System (CAPSS), Republic of Korea

II. METHODOLOGY

2.2 Ship Emission Estimation Methodology

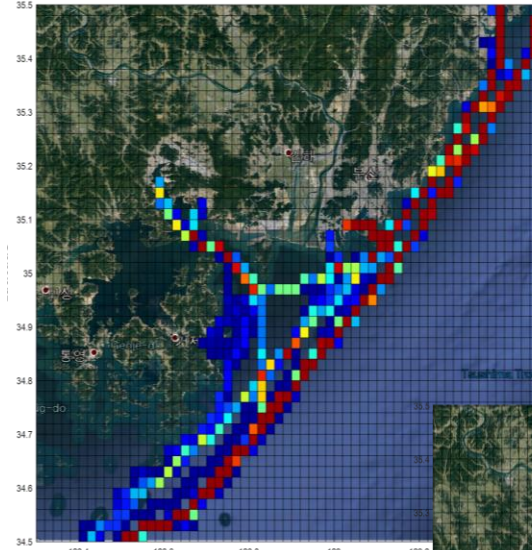


Fuel-based estimation



Activity-based estimation

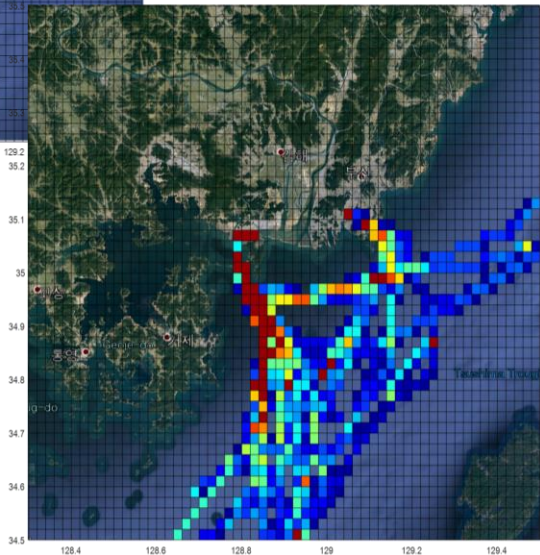
Clean Air Policy Support System (CAPSS)



Fuel & Activity-based estimation



AIS activity-based estimation



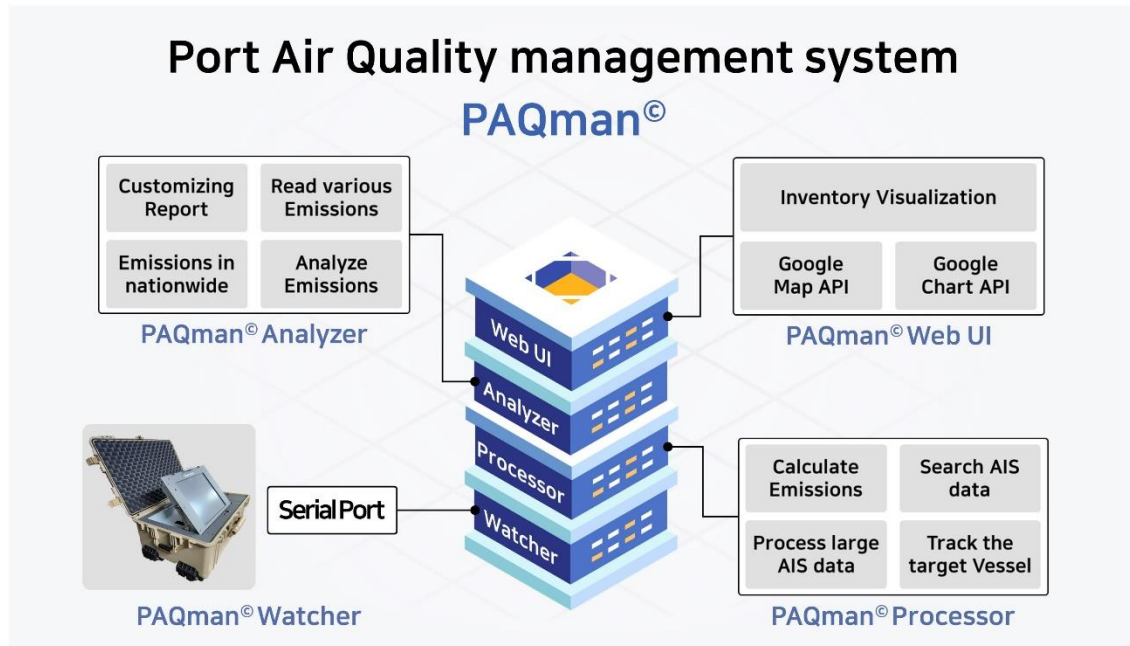
(Ref: EMEP/EEA air pollutant emission inventory guidebook 2019)

II. METHODOLOGY

2.3 Port-city Air Quality management system; PAQman[©]

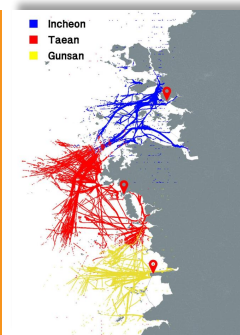


Port-city Air Quality management (PAQman[©]) system



PAQman[©] Collector

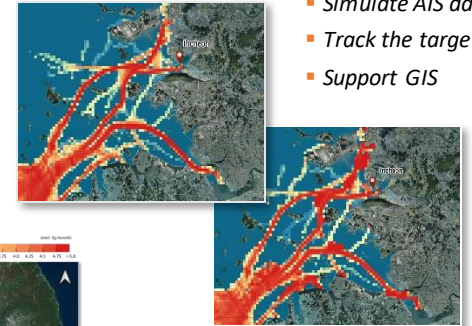
Collecting AIS data



- Setup communication
- Receive real time AIS data
- Manage regional AIS station (Incheon, Busan, Ulsan, Pyeongtack, etc.)
- Import AIS file, make DB
- Calculate real time total emissions

PAQman[©] Processor

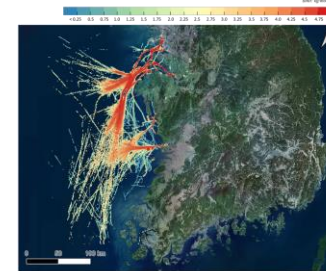
Calculate emissions



- Search AIS data
- Process large AIS data
- Simulate AIS data file
- Track the target vessel
- Support GIS

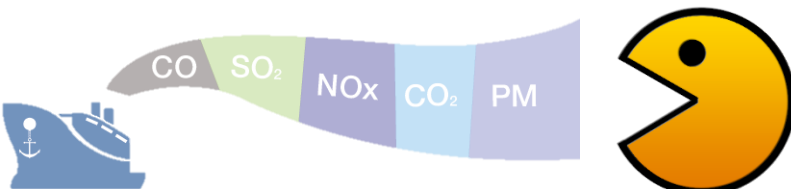
PAQman[©] Analyzer

Report and Printing



Ship PM_{2.5} emission based on the vessel movement (1 km mesh) in the Korean western coastal area

- Analyze emissions
- Customizing report format
- Emissions in nationwide
- Read various emissions
- Print analyzed contents

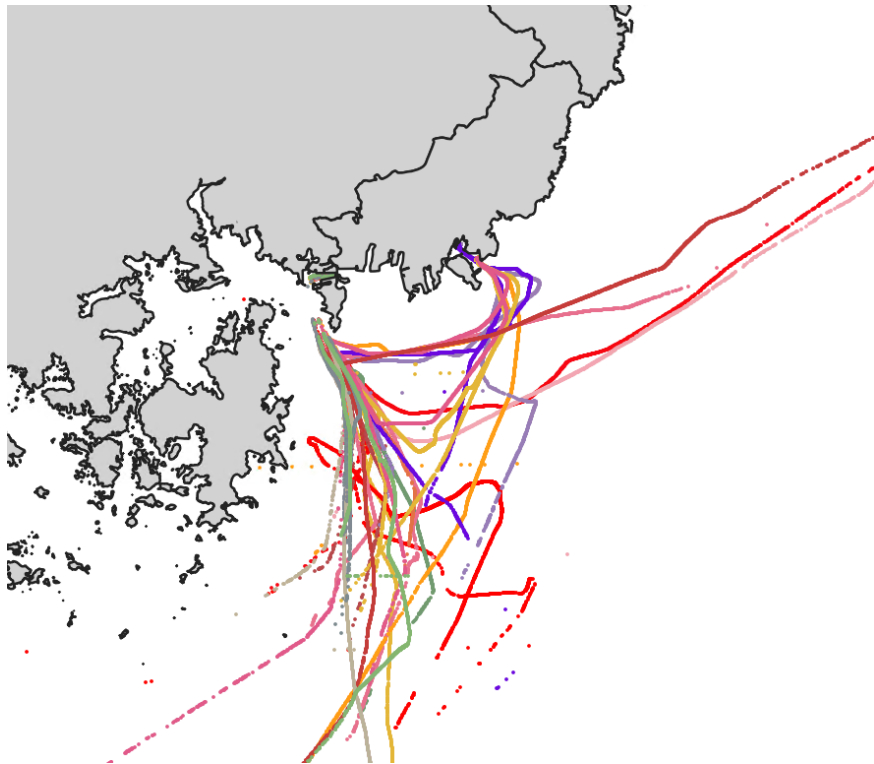


II. METHODOLOGY

2.4 AIS activity-based ship emission estimation methodology



Vessel real-time movement data
Automatic Identification System (AIS)



2020.06 ~ 2020.07
Container ship's AIS data in Busan

Container ship 'XXXXX' AIS & Specification variables

Variable	Sample data_n	Sample data_n+1
MMSI	212348000	212348000
SOG (unit: knot)	13.4	13.1
Latitude	34.25618	34.317167
Longitude	128.869983	128.913233
Time	2020-06-10 5:57	2020-06-10 6:16

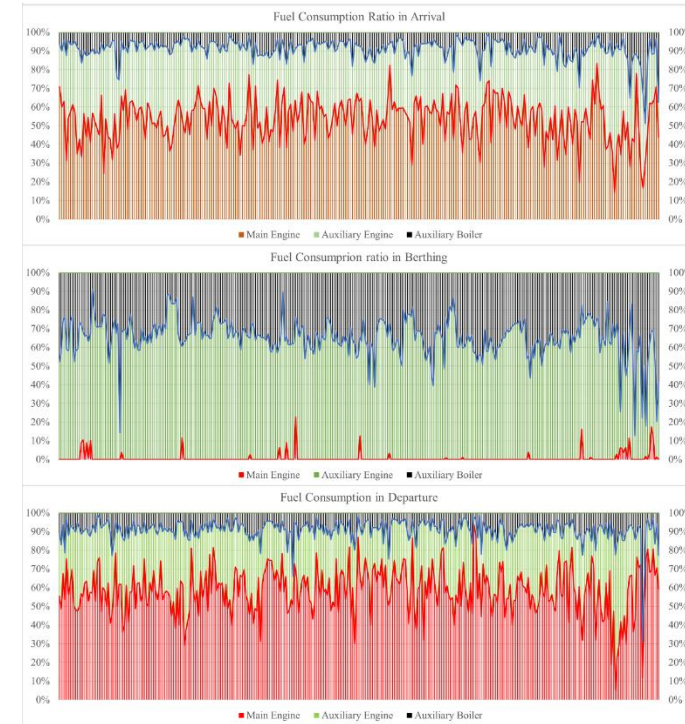
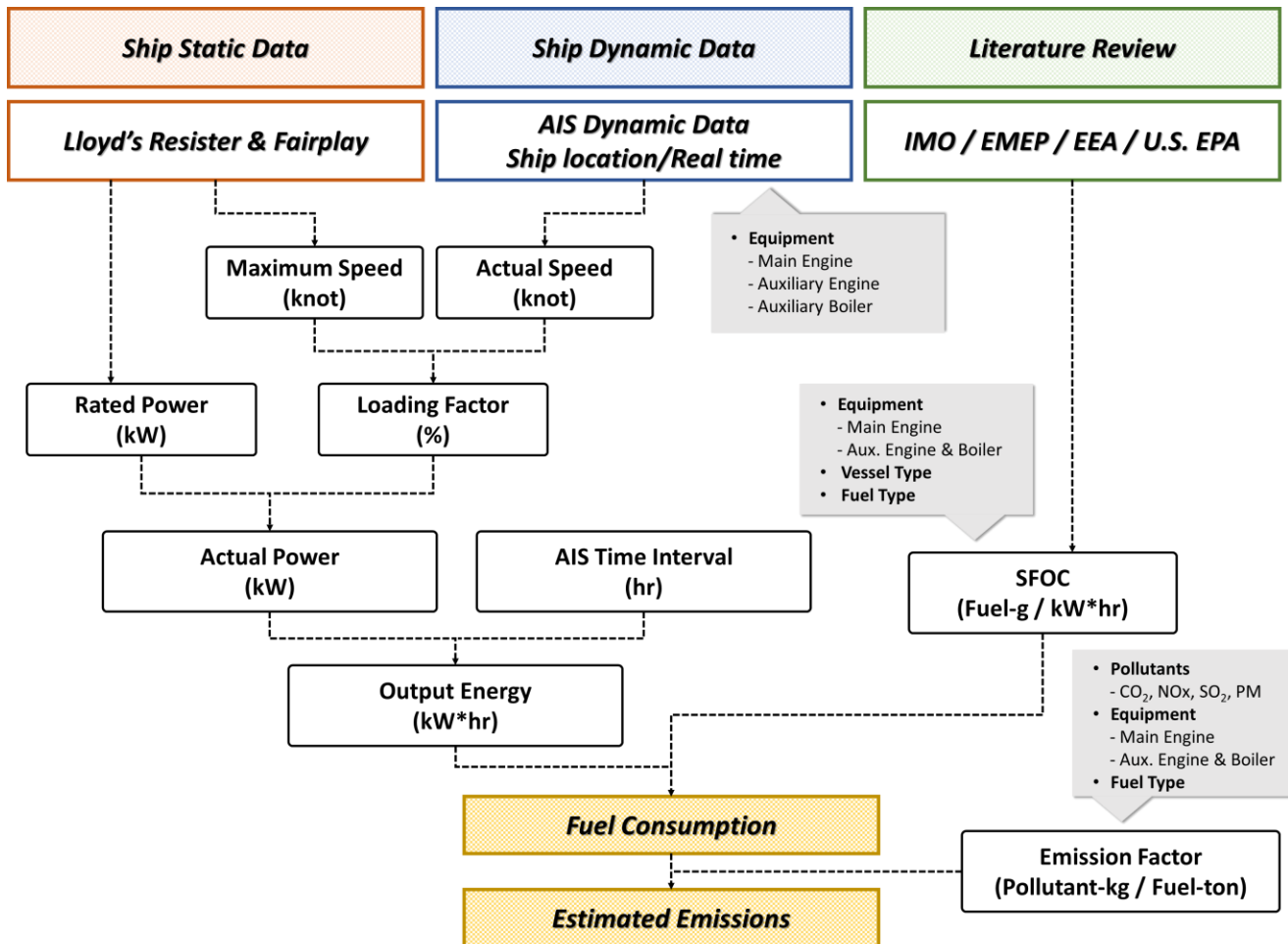
Vessel Specification Variable	Example
Ship Name	212348000
Ship Type	Container ship
Gross Tonnage (unit: ton)	74,651
Main Engine Power (unit: kW)	68,520
Auxiliary Engine Power (unit: kW)	12,540

II. METHODOLOGY

2.4 AIS activity-based ship emission estimation methodology



- Ship Emission Estimation Methodologies using real-time vessel movement data by AIS



- Vessel's engine machinery
 - Main Engine
 - Auxiliary Engine
 - Auxiliary Boiler

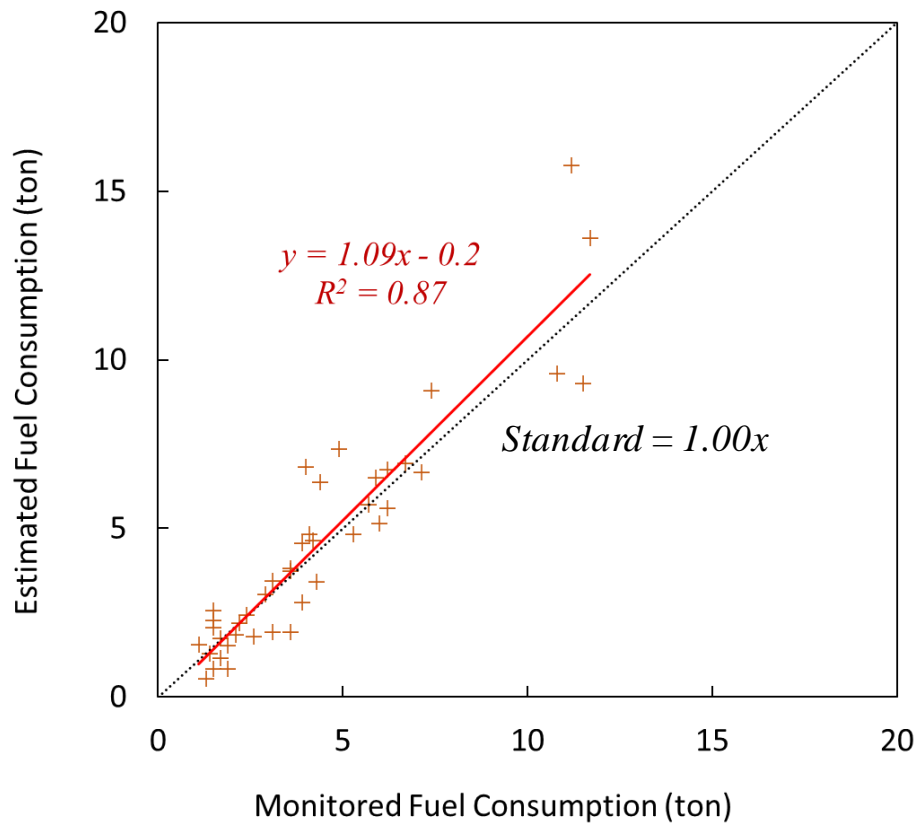
(Ref: Air/Climate Group, Incheon National University)

III. RESULT AND DISCUSSION

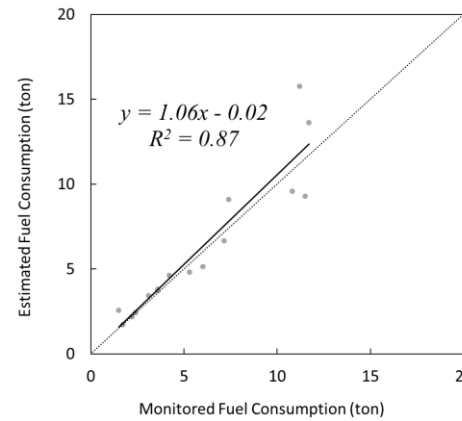
3.1 Validation study of AIS-based estimation methodology



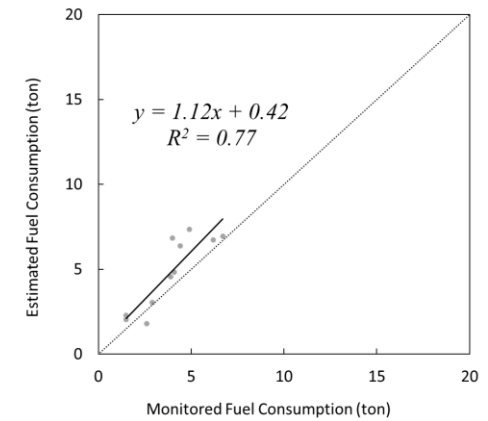
- Monitored vs. Estimated the Fuel consumption



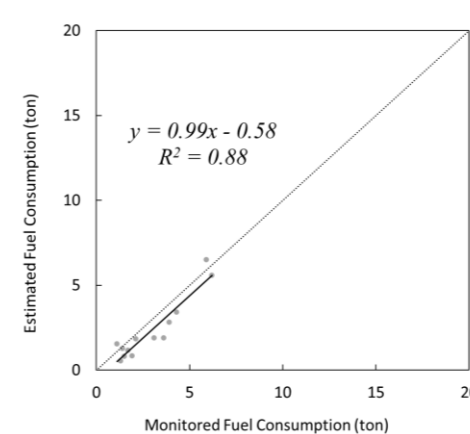
Hotelling mode



Arrival mode

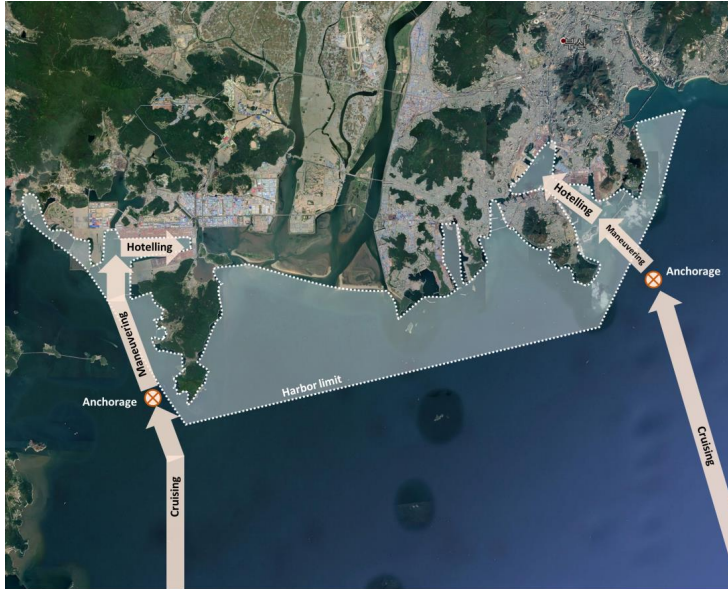


Departure mode

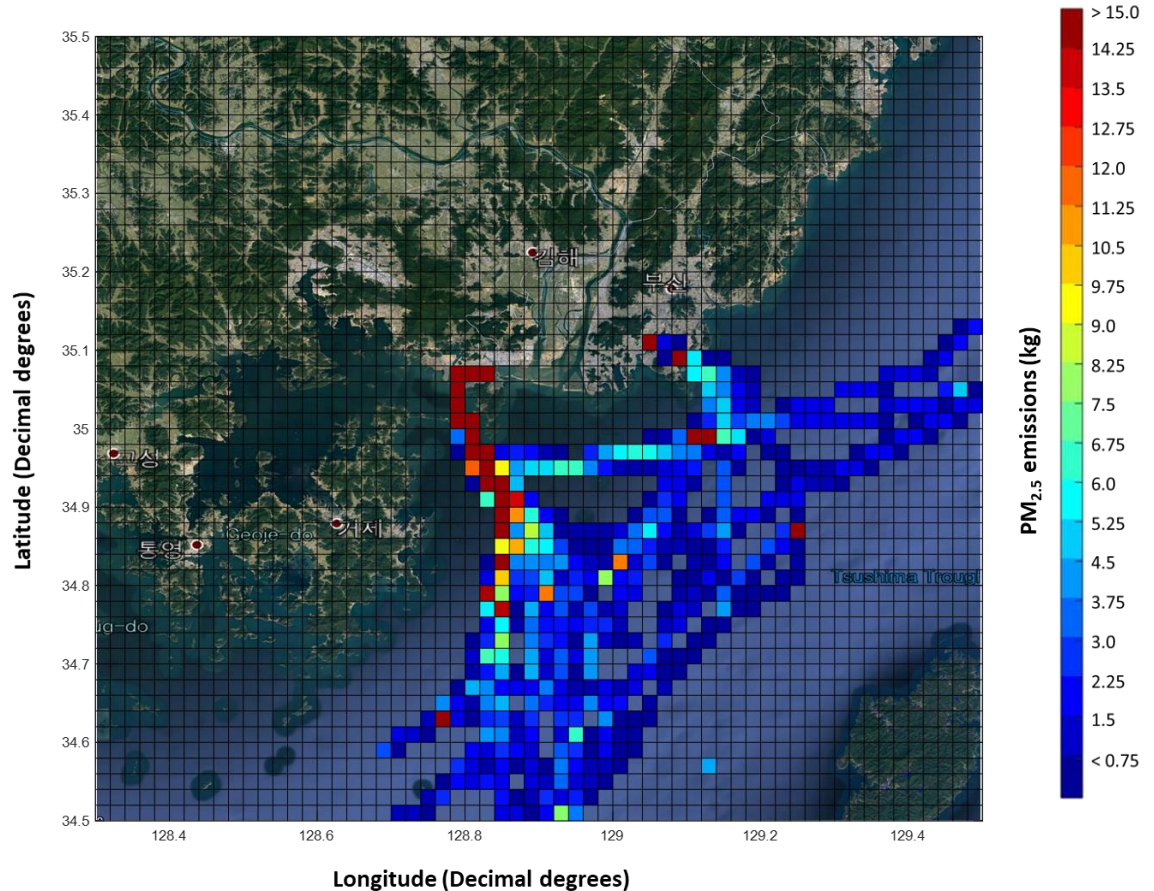


III. RESULT AND DISCUSSION

3.2 PM_{2.5} emissions of Container ships in Busan port area



(a) General operation modes in Busan port area



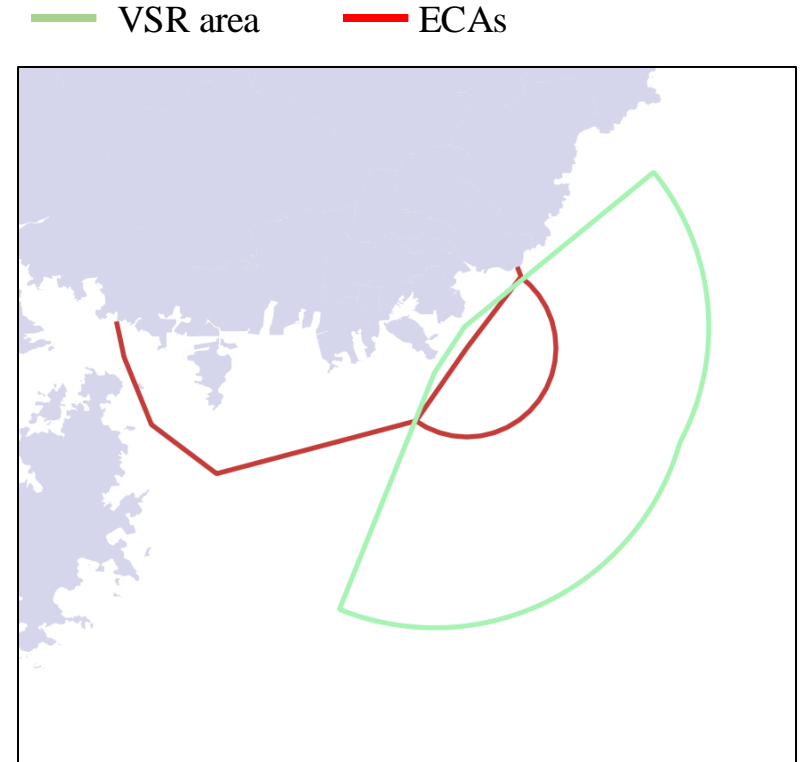
(b) Ship PM_{2.5} emission based on the vessel movement (1 km mesh)

III. RESULT AND DISCUSSION

3.4 Reduction potential of ship emission regulation

Scenario for reduction policies of ship emissions

- **Scenario 0**
 - Before 2020 / No Regulation
- **Scenario 1**
 - 2020.01.01 ~ 2020.08.30
 - IMO 2020 → sulfur content of marine fuel oil (3.5% → 0.5% m/m)
 - Vessel Speed Reduction (VSR) program → container ship max speed limit 12 knots
- **Scenario 2**
 - 2020.09.01 ~
 - Emission Control Areas (ECAs) in Busan → sulfur content (0.5% → 0.1% m/m)
 - Vessel Speed Reduction (VSR) program
- **Scenario 3**
 - 2030.01.01 ~
 - Emission Control Areas (ECAs) in Busan
 - Vessel Speed Reduction (VSR) program
 - Alternative Maritime Power supply (AMP)

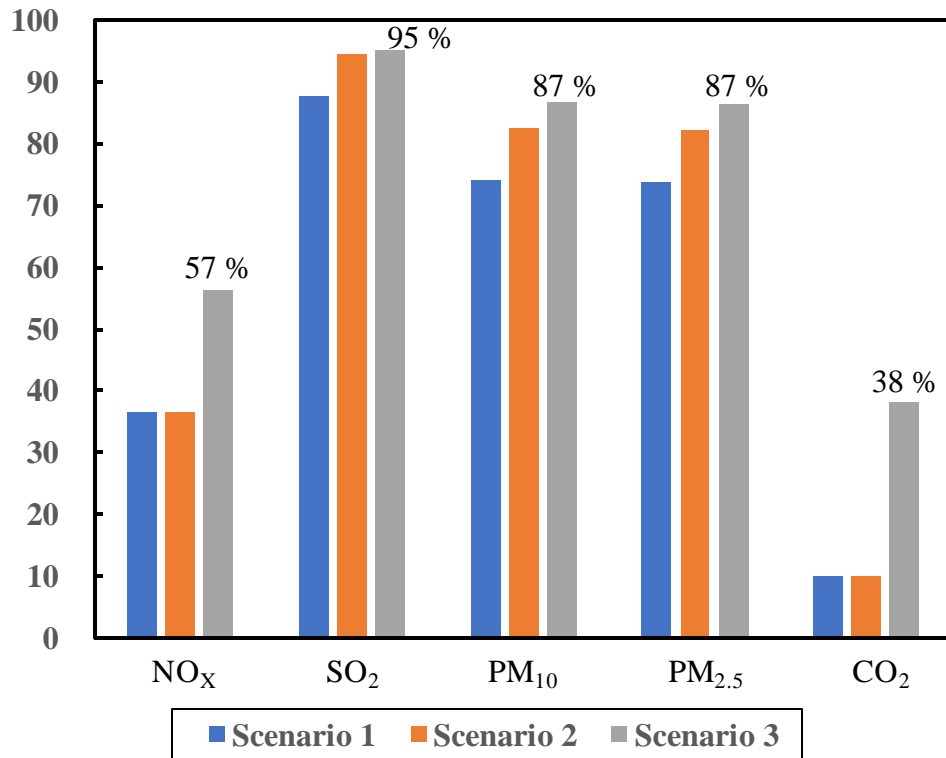


Ship air emission estimation area
in this study

III. RESULT AND DISCUSSION

3.4 Reduction potential of ship emission regulation

- Reduction potential of ship emission regulation by scenario

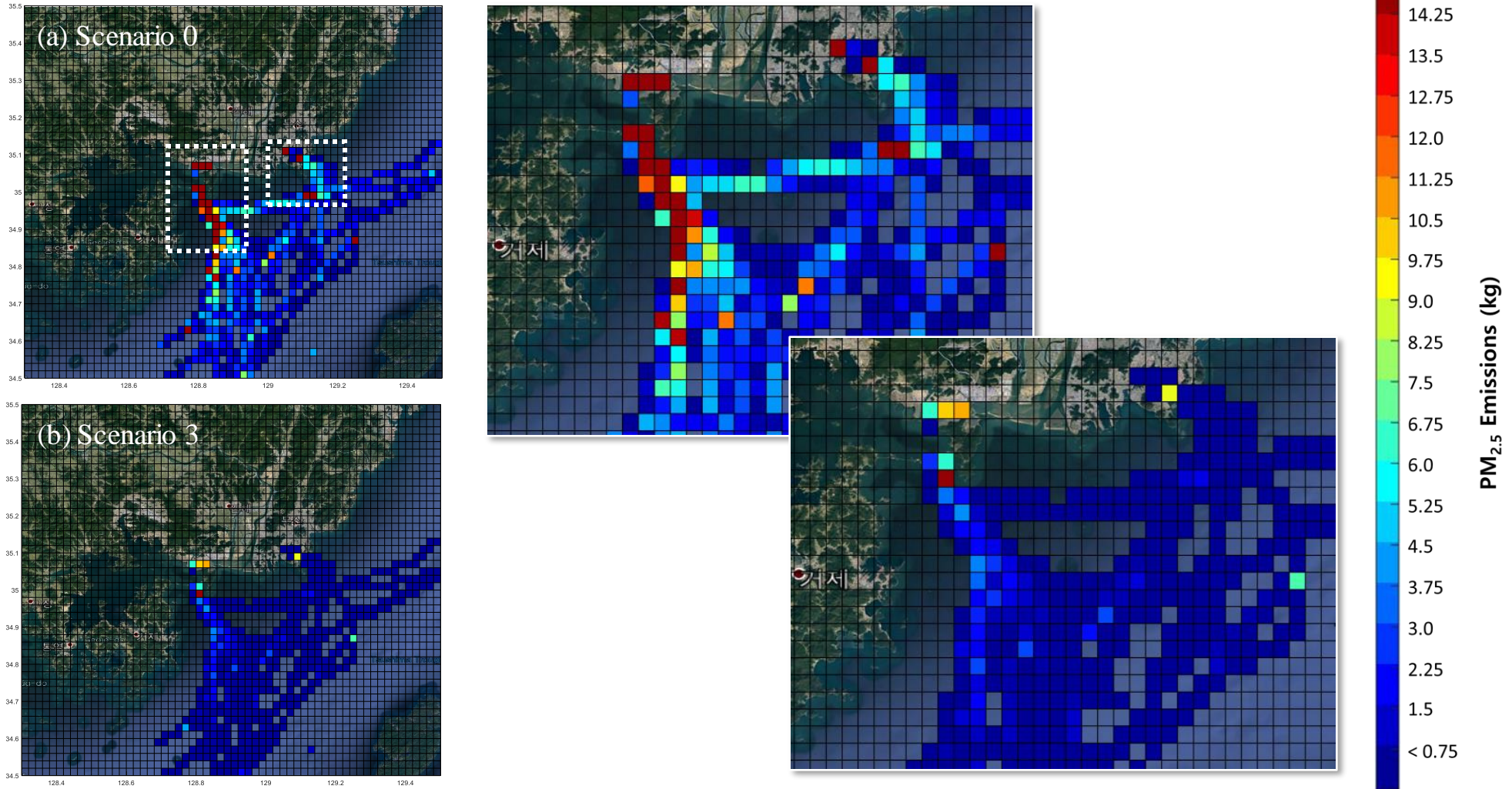


Scenario	Ship emissions (ton)				
	NO _x	SO ₂	PM ₁₀	PM _{2.5}	CO ₂
Scenario 0	34.3	30.3	2.68	2.42	1,347
Scenario 1	21.8	3.7	0.69	0.63	1,214
Scenario 2	21.8	1.63	0.46	0.43	1,214
Scenario 3	14.9	1.44	0.35	0.32	831

III. RESULT AND DISCUSSION

3.4 Reduction potential of ship emission regulation

- High-resolution map of ship emission by scenario in Busan



IV. CONCLUSION



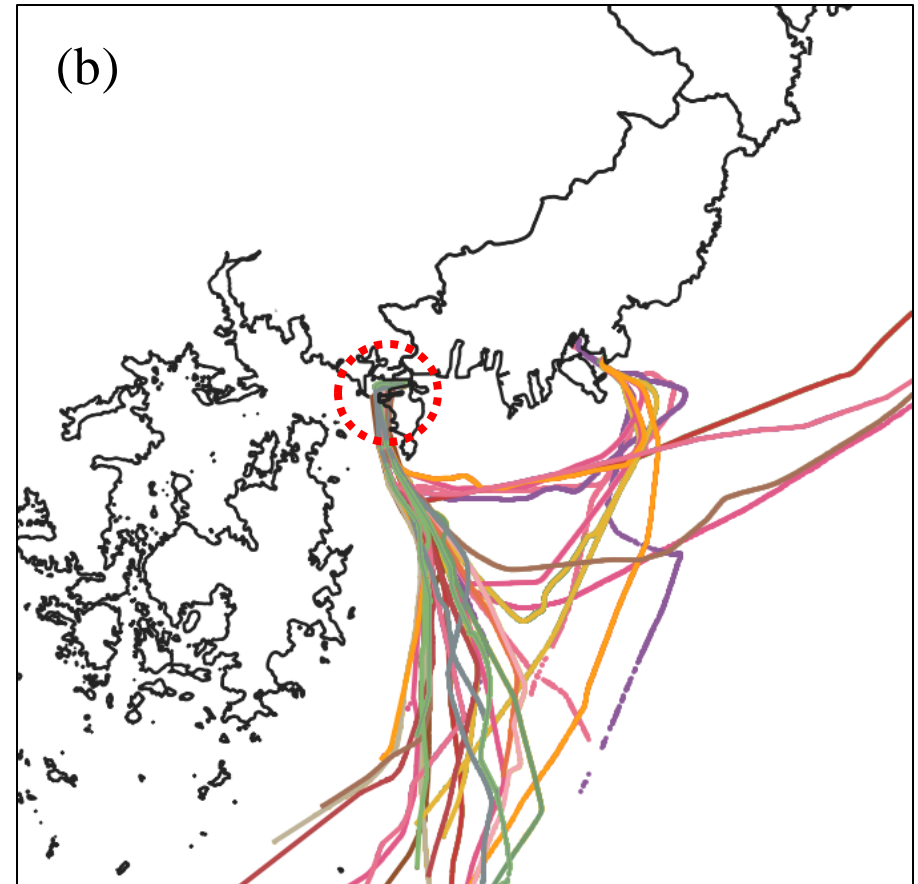
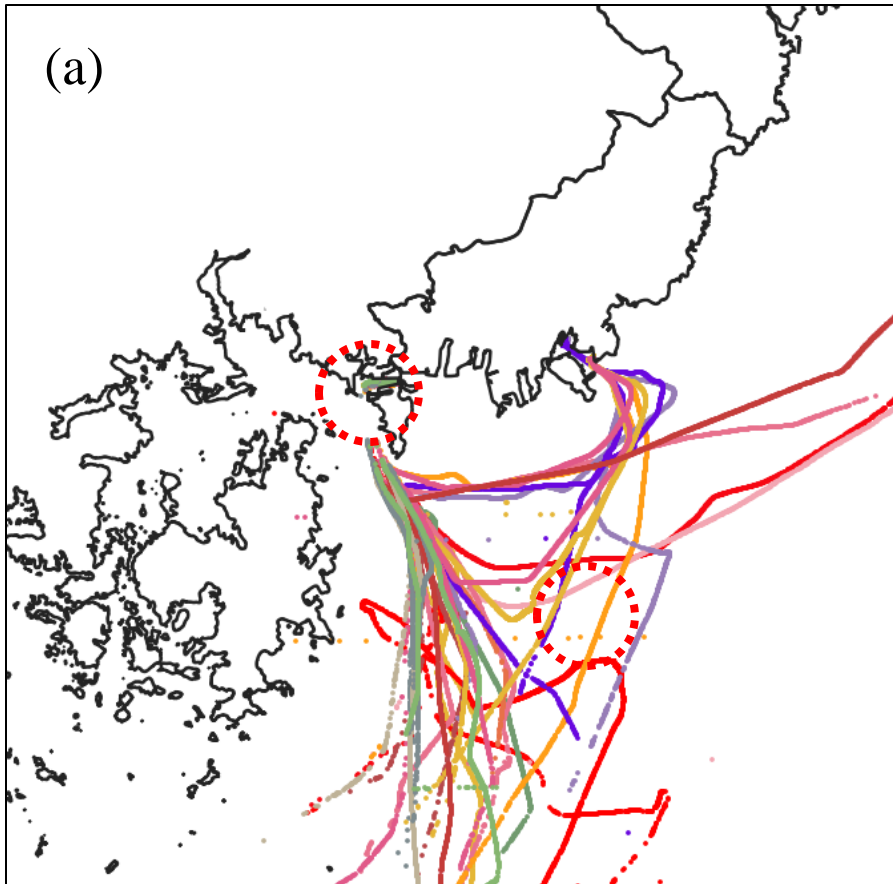
Objectives	<ul style="list-style-type: none">• To estimate qualitative ship air emissions inventory applying AIS activity-based approach in Busan port area• To validate ship emission inventory methodology with monitored data for reliable city-level ship emission inventory
Results	<ul style="list-style-type: none">▪ As a result of AIS-based estimation, the result was about 1.1 times higher than monitored data▪ As a result of ship emission estimation by CAPSS, the result was about 2.5 ~ 2.9 times higher than monitored data▪ As a result of reduction potential, the most of air pollutant was reduced through the policies for reducing ship emission in Busan port.
Conclusion	<ul style="list-style-type: none">▪ General outcome of this study provides better ship air emission inventory methodology for beneficial management of port-city air quality▪ Also, we can analyze precisely political effects for reducing ship emissions based on the AIS-based ship emission inventory.▪ Finally, a mechanism of ship air emission inventory methodology need to shift from based-on statistics to AIS-based real time ship emission estimation methodology



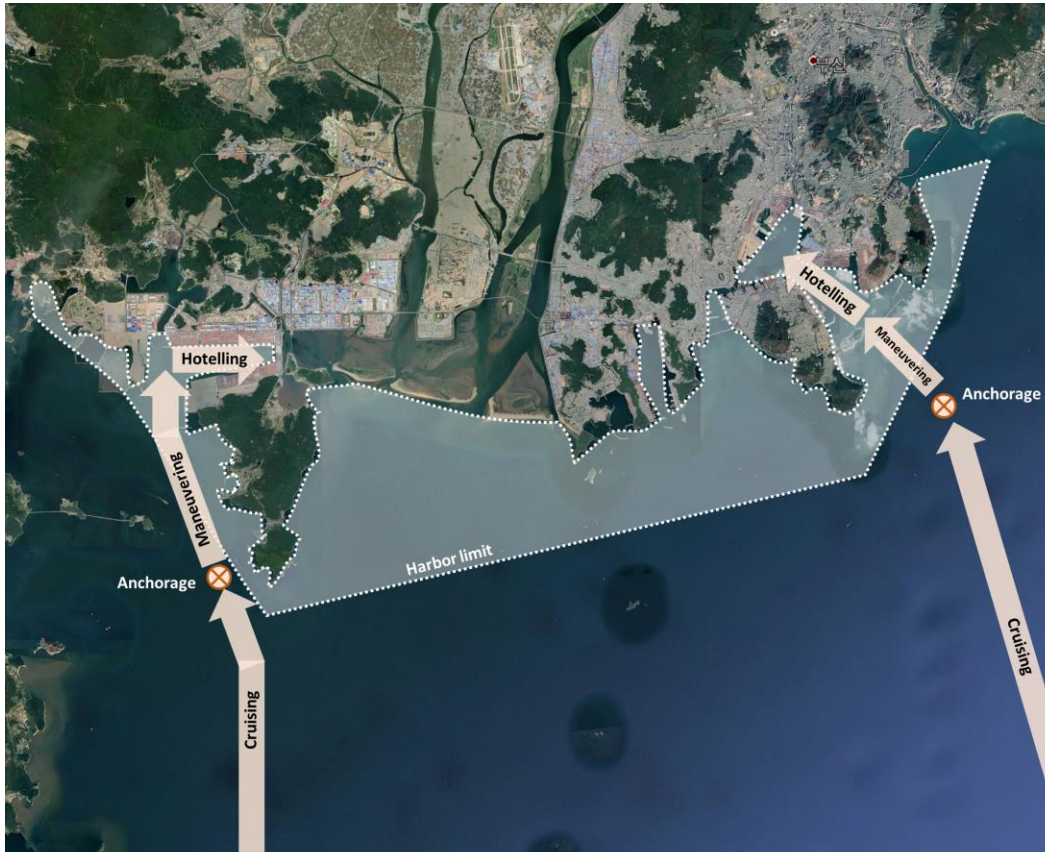
Contact: Yongchan Lee
Department of Environmental Engineering
Incheon National University
Jehun1108_m@inu.ac.kr

Preprocess of Automatic Identification System (AIS)

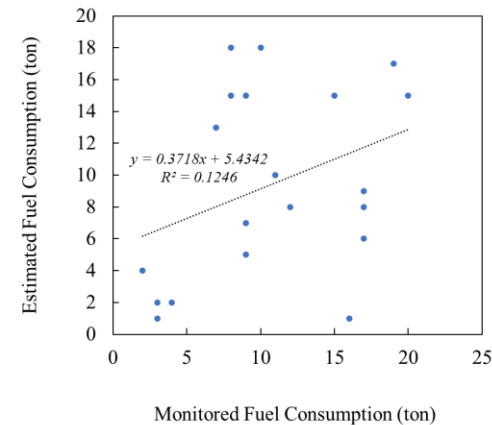
- Remove the error of location coordinate from GPS
- Interpolate linearly missing data



■ Vessel's operation mode



- Validation study of AIS-based estimation
 - Standard : Monitored fuel consumption
 - Comparison : AIS-based fuel consumption



Example

Slope : 0.37

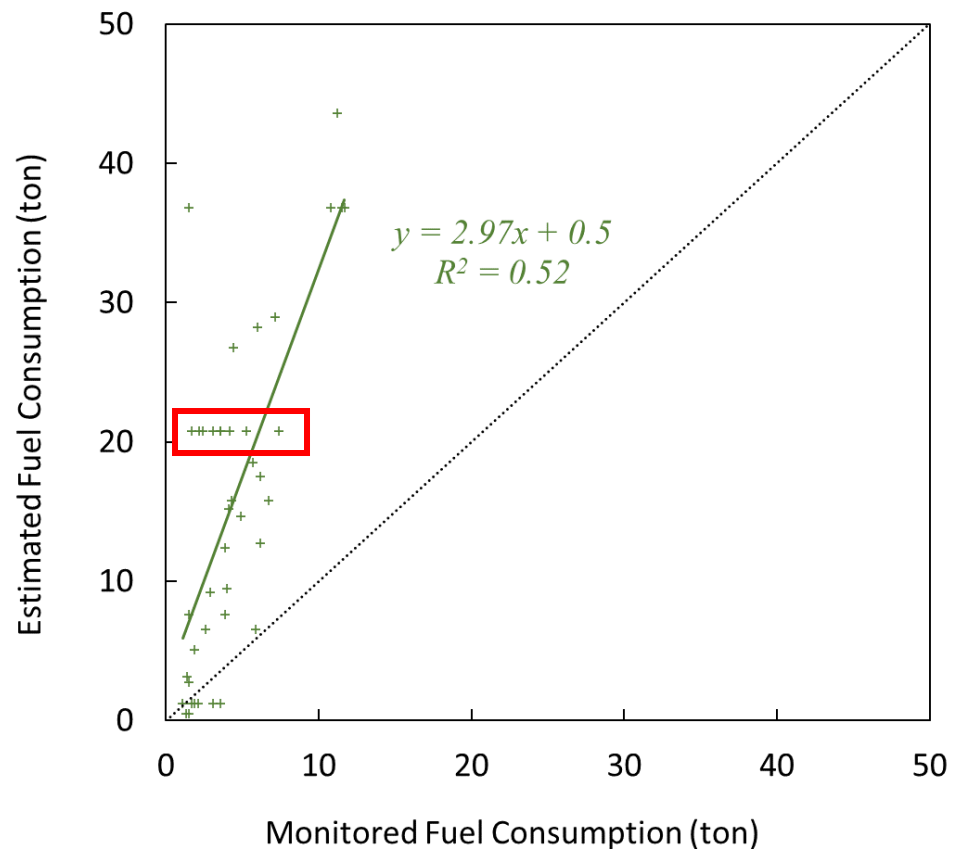
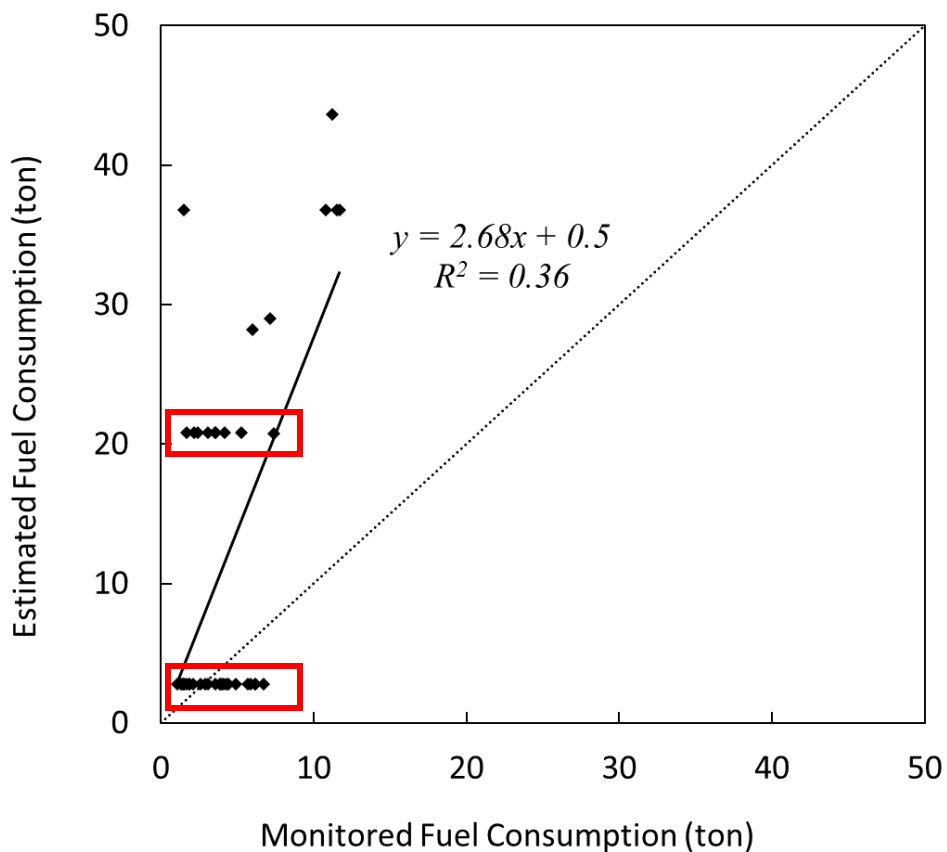
Coefficient of determination (R^2) : 0.12

■ Operation mode

- Hotelling mode
- Maneuvering-arrival mode
(Maneuvering + Cruising)
- Maneuvering-departure mode
(Maneuvering + Cruising)

3.3 Validation study of ship emission estimation method in CAPSS

- Ship emission estimation for central government by Clean Air Policy Support System (CAPSS)



3.3 Validation study of ship emission estimation method in CAPSS

- Ship Emission Estimation Methodologies using Arrival/Departure statistics by PORT-MIS (PORT-MIS; PORT Management Information System, *Ministry of Oceans and Fisheries, MOF*)

Operation Phase	Low resolution PORT-MIS DB Method A	High resolution PORT-MIS DB Method B
Berth	$\text{Fuel Consumption(ton)} = N \times \text{SFOC (ton/day)} \times 0.79 \text{ (day/N)} \times 0.2$ <ul style="list-style-type: none"> * N : Number of Ship calling in the Port * SFOC : Specific Fuel Oil Consumption in Maximum Power according to Gross Tonnage (ton/day) (Ref: EEA(1999), EMEP/CORINAIR Emission Inventory Guidebook-1999) * <u>0.79 : Average number of Berthing day (day/N)</u> (Ref: Result of sample research of 560 vessels arrival Ulsan port in January and December 2001) * <u>0.2 : Assume 20% output at berth relative to maximum power (Loading Factor)</u> (Ref: EEA(1999), EMEP/CORINAIR Emission Inventory Guidebook-1999) 	
Maneuvering	$\text{Fuel Consumption(kL)} = N \times \text{Cruise Distance(km)} \div \text{Fuel Economy(km/kL)}$ <ul style="list-style-type: none"> * <u>Cruise Distance : 35km of sea breeze impact in batch</u> (Ref: Korea Energy Economics Institute) 	$\text{Fuel Consumption(kL)} = N \times \text{Pilotage Distance(km)} \div \text{Fuel Economy(km/kL)}$ <ul style="list-style-type: none"> * <u>Pilotage Distance : pilotage distance by port</u> * Fuel Economic : Fuel economy data by Gross tonnage (Ref: Korea Energy Economics Institute)
Cruising	<ul style="list-style-type: none"> * N : Number of Ship calling in the Port * <u>Cruise Distance : 35km of sea breeze impact in batch</u> (Ref: Korea Energy Economics Institute) * Fuel Economic : Fuel economy data by Gross tonnage (Ref: Korea Energy Economics Institute) 	$\text{Fuel Consumption(ton)} = \text{Engine Power(kW)} \times \text{SFOC (g/kWh)} \times 0.8 \times \text{HRS(h)} \times 10^{-6}$ <ul style="list-style-type: none"> * SFOC : Specific Fuel Oil Consumption by engine power (Ref: EMEP/CORINAIR Emission Inventory Guidebook-2009) * <u>0.8 : Assume 80% output at berth relative to rated power</u> (Ref: EMEP/CORINAIR Emission Inventory Guidebook-2009) * HRS : Record of Arrival/Departure in PORT-MIS

(Ref: National Air Pollutants Emission Service)

❖ PAQman-Watcher system



**Stationary
PAQman-Watcher
(Rack mount)**

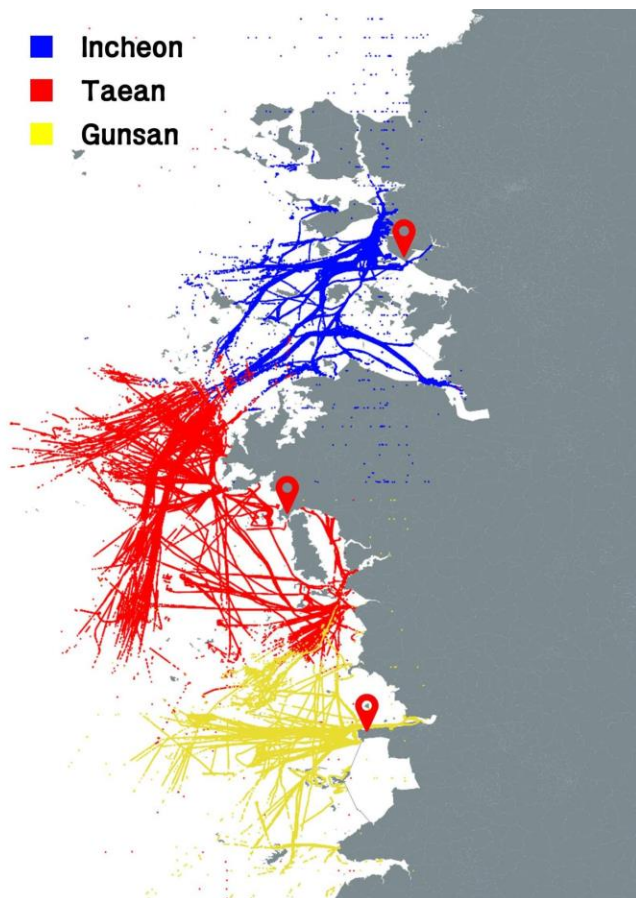


**Mobile
PAQman-Watcher
(Pelican case)**



**Portable
PAQman-Watcher
(Pelican case)**

Vessel real-time movement data
Automatic Identification System (AIS)

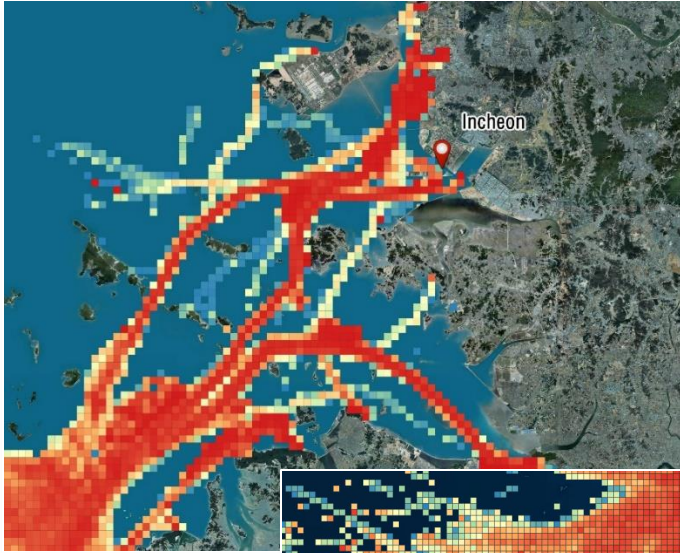


Vessel 'XXXXXX' AIS & Specification variables

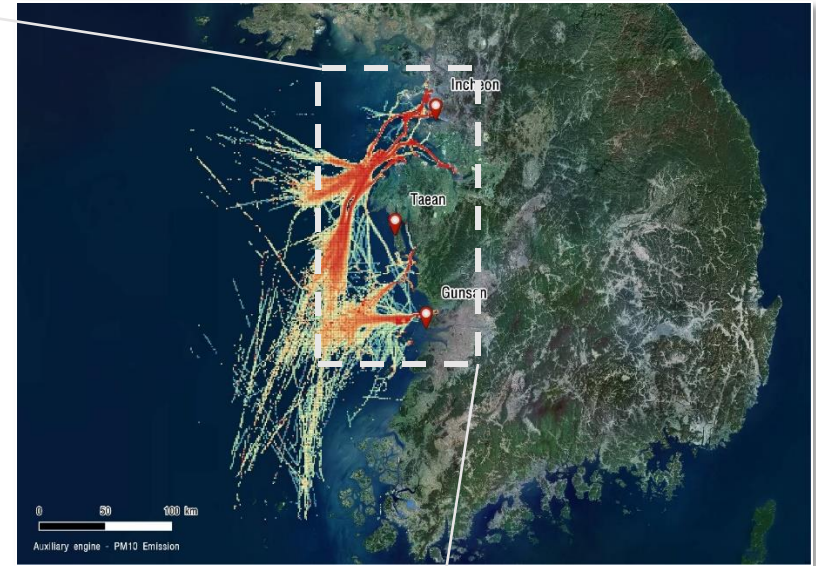
Variable	Sample data_n	Sample data_n+1
MMSI	xxxxxx	xxxxxx
SOG (unit: knot)	17.1	17.2
Latitude	36.24382	36.24814
Longitude	125.8553	125.8578
Time	2021-11-15 21:36:30	2021-11-15 21:37:30

Vessel Specification Variable	Example
Ship Name	xxxxxx
Ship Type	Container ship
Gross Tonnage (unit: ton)	18,658
Main Engine Power (unit: kW)	11,720
Auxiliary Engine Power (unit: kW)	3,660

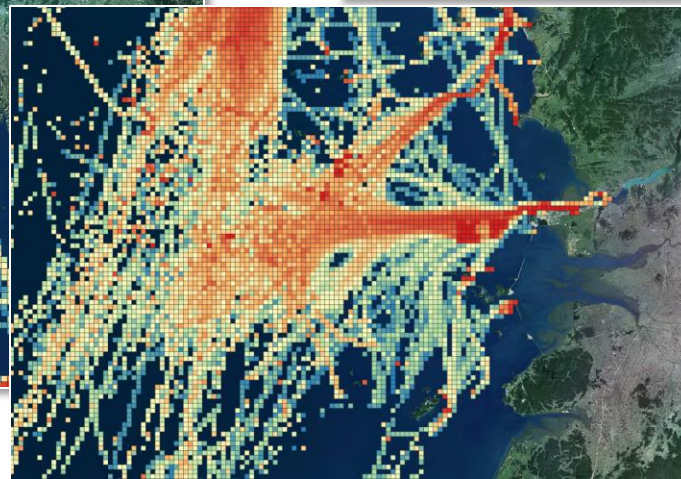
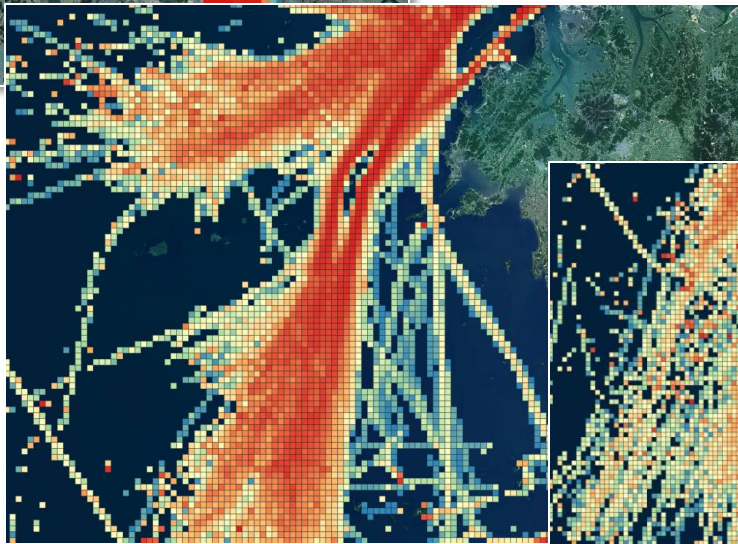
Ship air emission inventory using PAQman



Ship PM_{2.5} emission map in Incheon



Ship PM_{2.5} emission map in Taean



Ship PM_{2.5} emission map in Gunsan