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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

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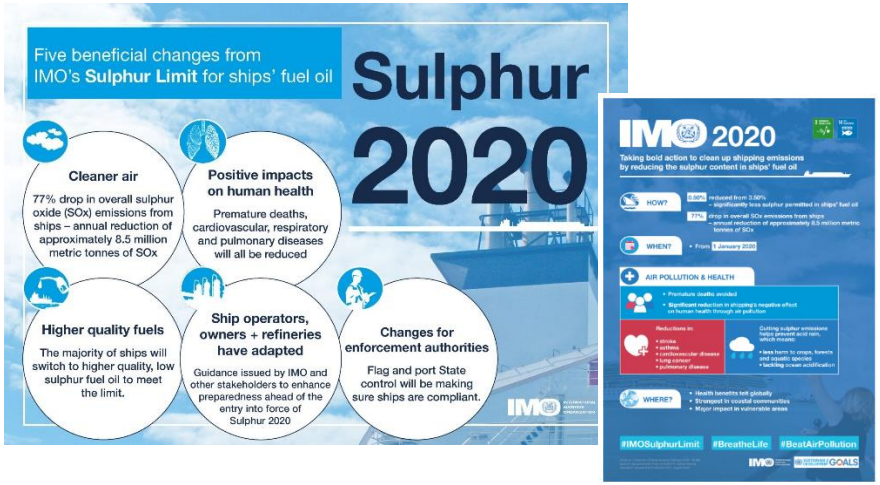
INCHEON NATIONAL UNIVERSITY

Contents

Increased demand for enhanced management of ship air pollutants in port

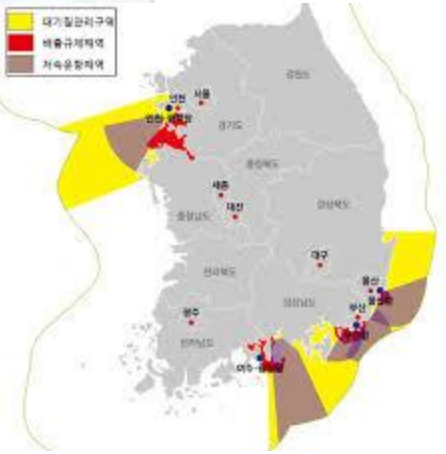
- Particulate matter is classified as highly hazardous substance by International Agency for Research on Cancer due to the mutagenic and carcinogenic agent
- Portion of air pollution from vessel in the Port-city occupies the largest

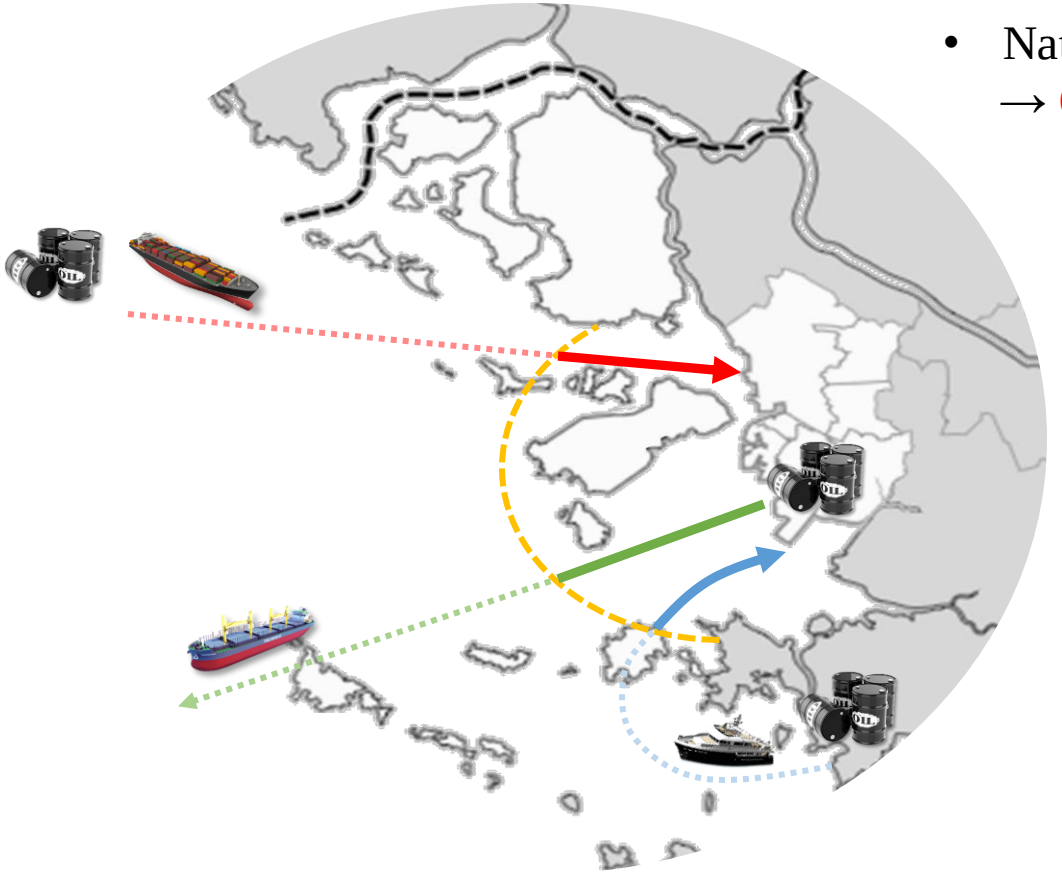
- International Maritime Organization (IMO) has addressed beneficial implementation such as sulfur limit of vessel fuel oil, GHGs reduction and determination of emission control area (ECA)



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



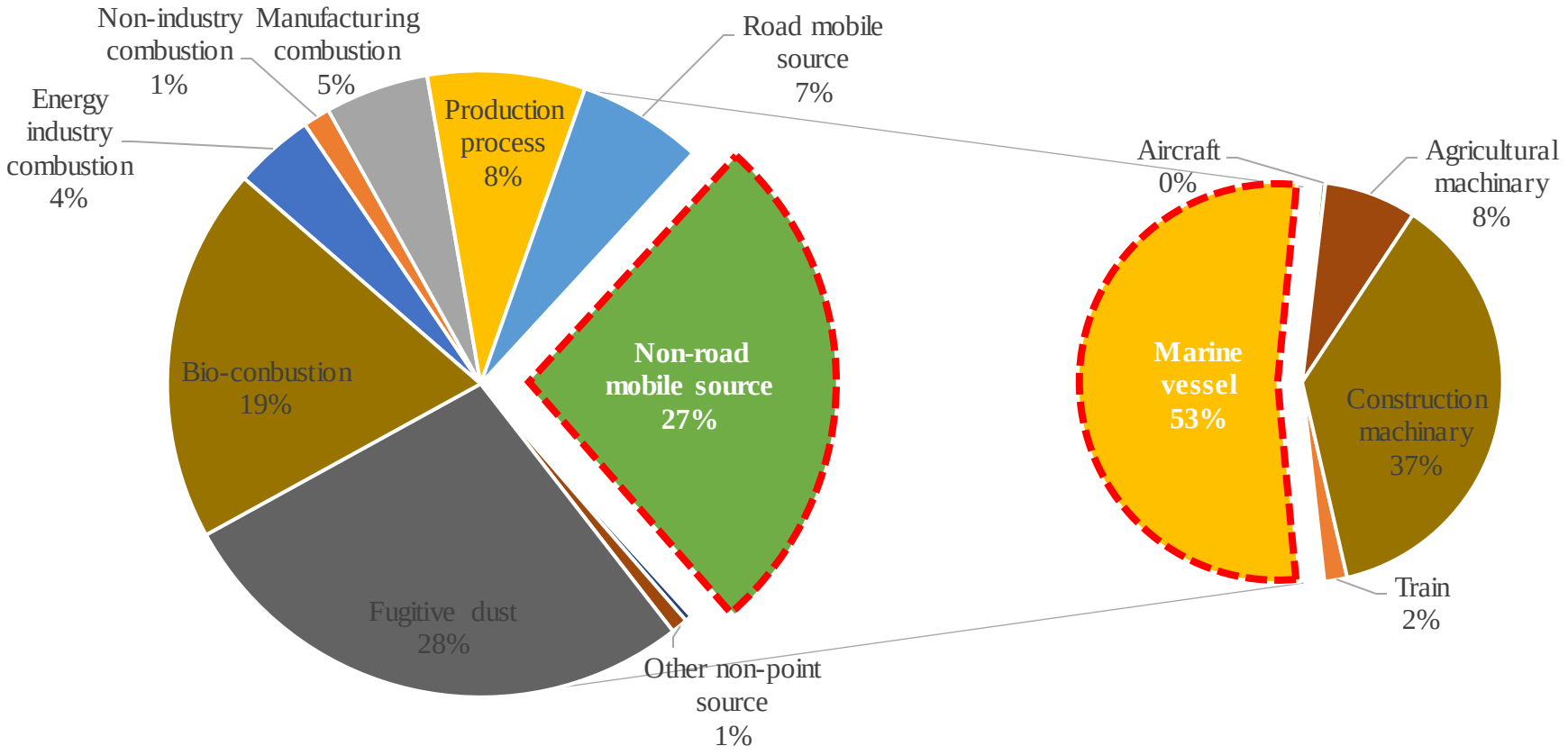


- National guideline - Fuel based (Tier 2) Estimation
  → Overseas-bunkered foreign vessels / other-port-bunkered domestic vessels (sailing overseas/other ports) are excluded to estimate ship emissions

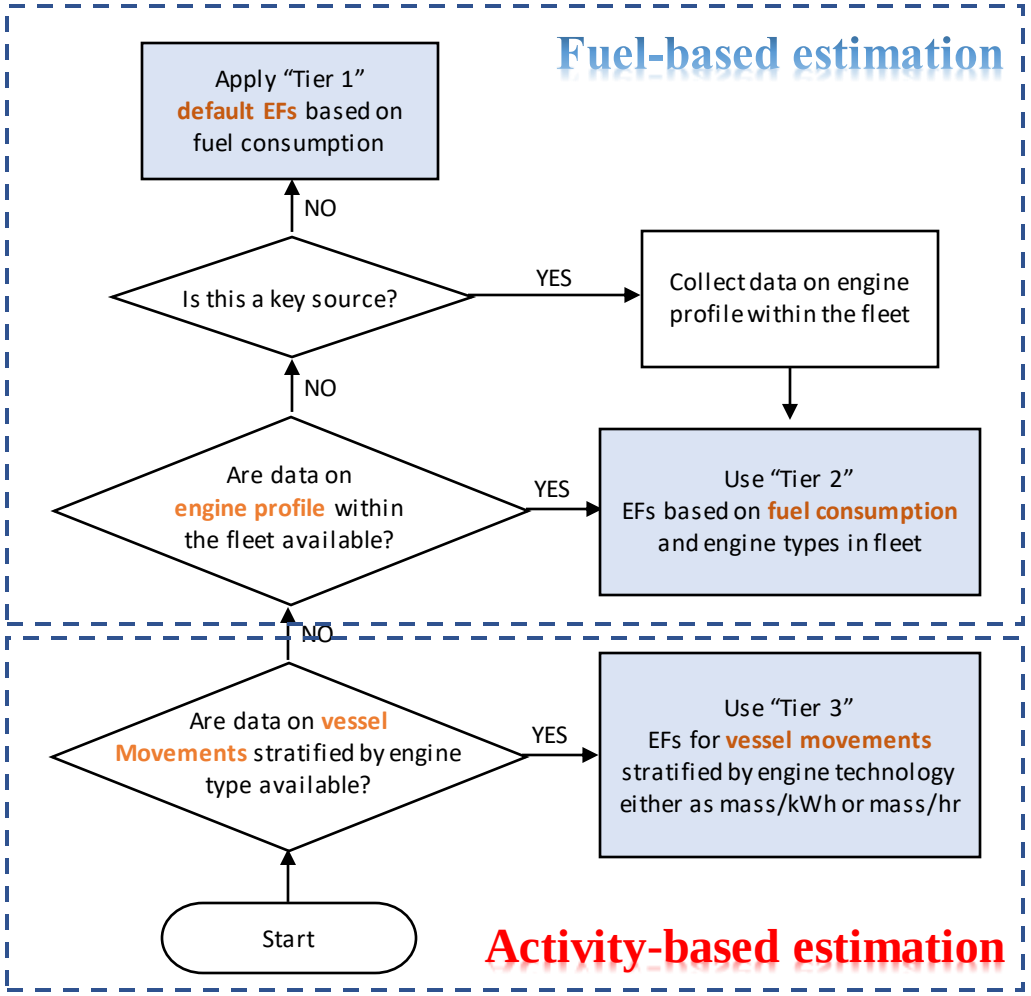
	Inner harbor limit	Outer harbor limit
Domestic vessel	**Counted !!**	
Foreign vessel		**Unknown !!**

2.1 Characteristics of study area

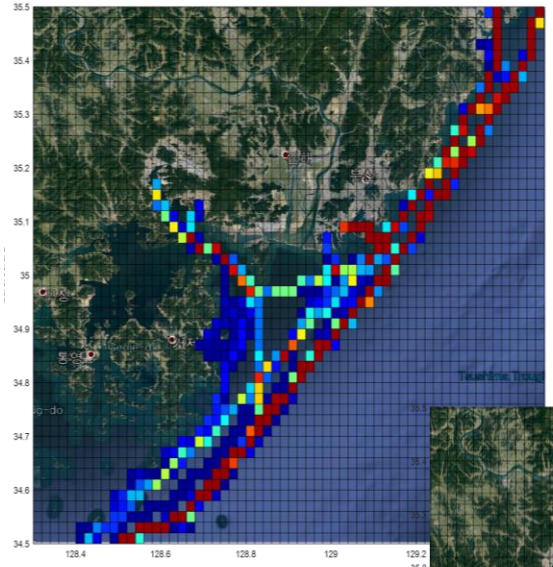
(Unit: kg/year)



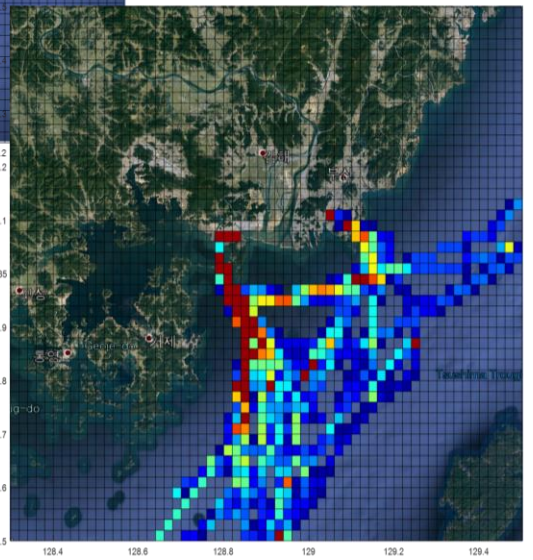
2020 $PM_{2.5}$ Emission Inventory from
Clean Air Policy Support System (CAPSS), Republic of Korea



Clean Air Policy Support System (CAPSS)



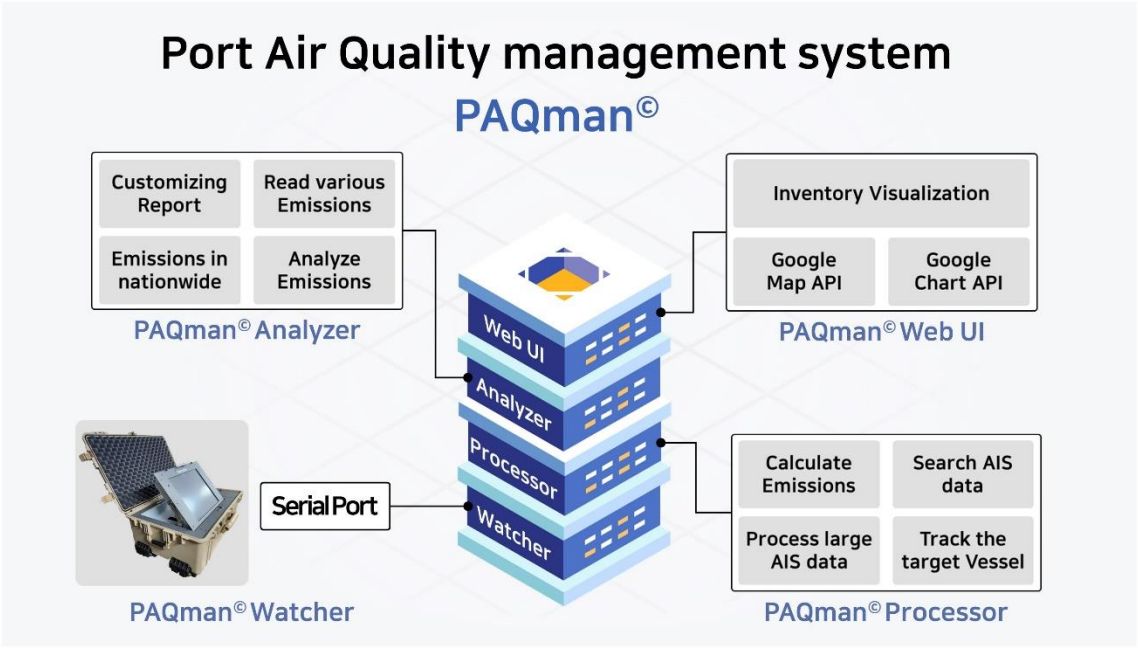
Fuel & Activity-based estimation



AIS activity-based estimation

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

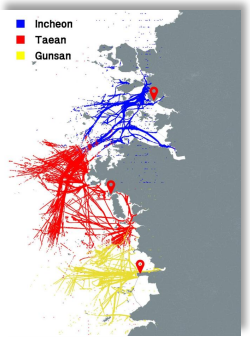
Port-city Air Quality management (PAQman©) system



PAQman© Collector

Collecting AIS data

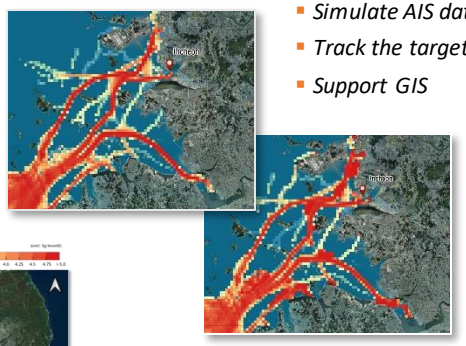
- *Setup communication*
- *Receive real time AIS data*
- *Manage regional AIS station (Incheon, Busan, Ulsan, Pyeongtack, etc.)*
- *Import AIS file, make DB*
- *Calculate real time total emissions*



PAQman© Processor

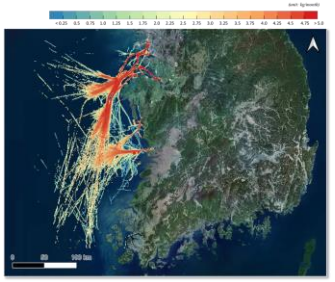
Calculate emissions

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



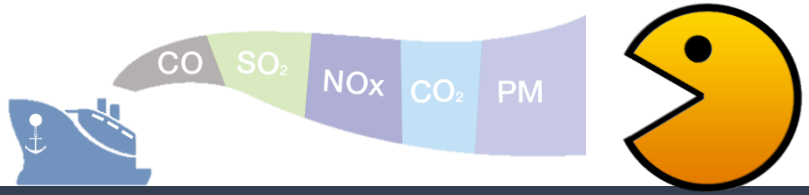
PAQman© Analyzer

Report and Printing



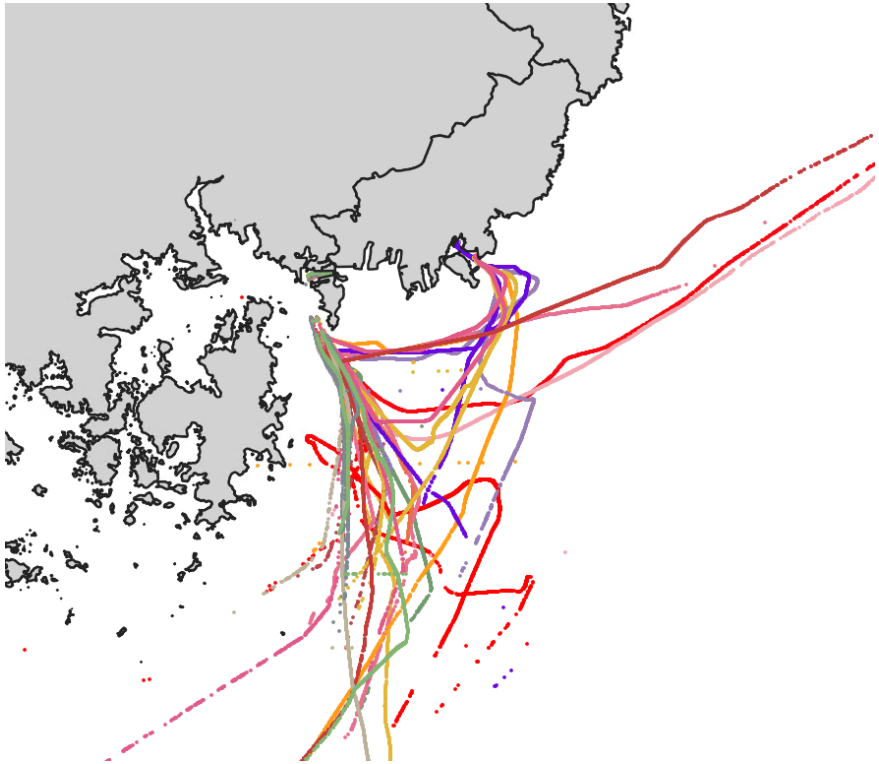
Ship $PM_{2.5}$ emission based on the vessel movement (1 km mesh) in the Korean western coastal area

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



2.4 AIS activity-based ship emission estimation methodology

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



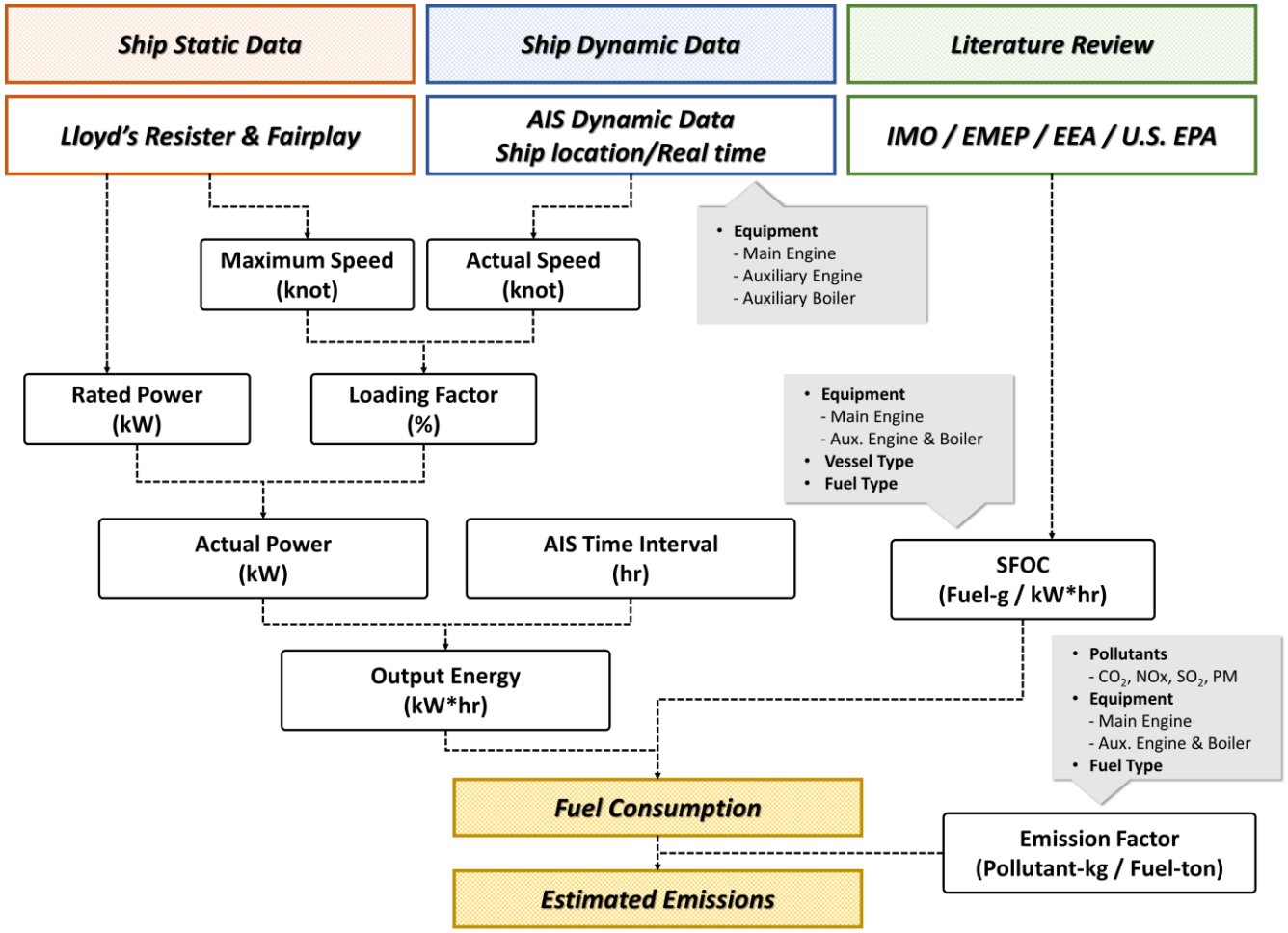
2020.06 ~ 2020.07
Container ship's AIS data in Busan

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

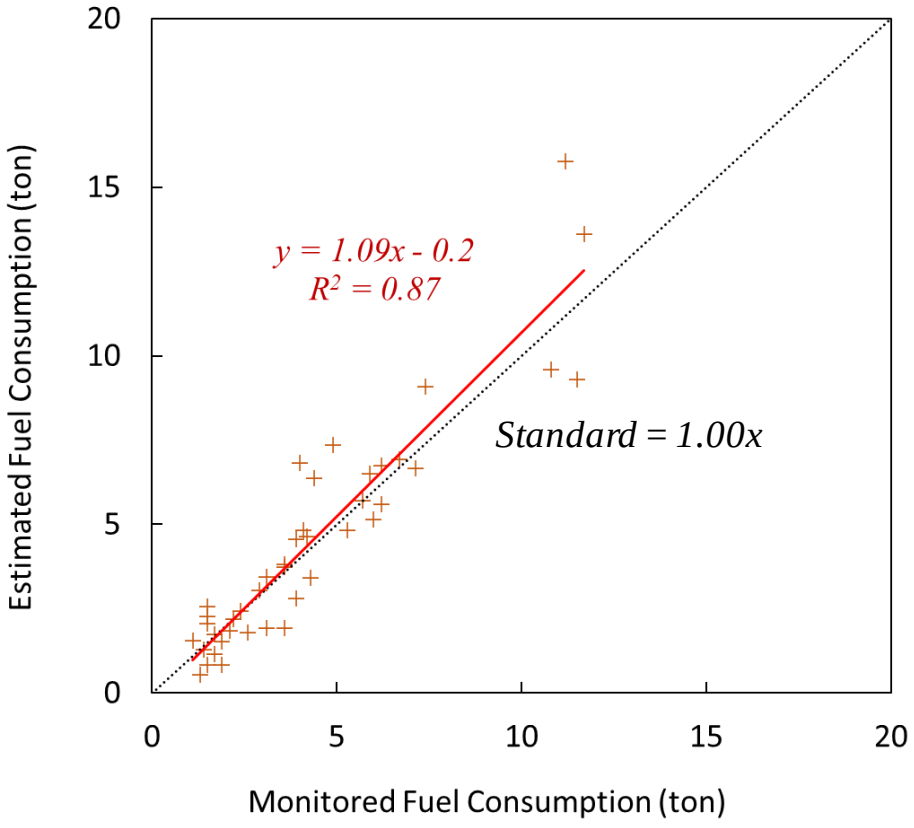
- Ship Emission Estimation Methodologies using real-time vessel movement data by AIS



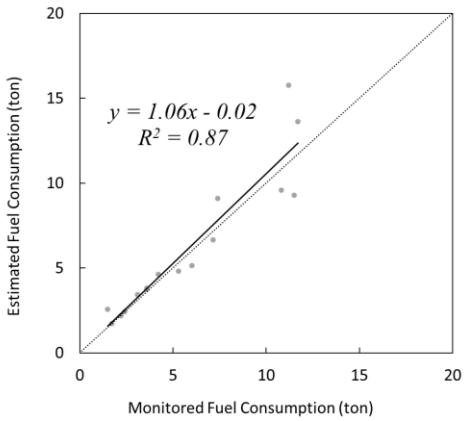
- Vessel's engine machinery
  - Main Engine
  - Auxiliary Engine
  - Auxiliary Boiler

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

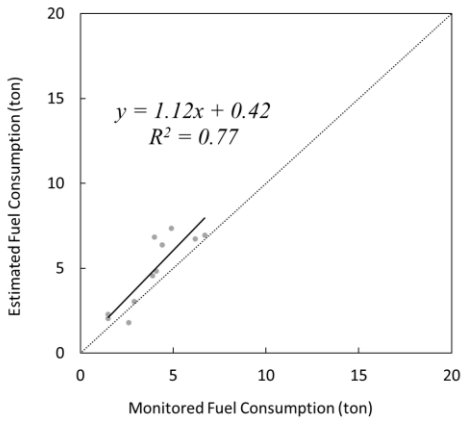
- Monitored vs. Estimated the Fuel consumption



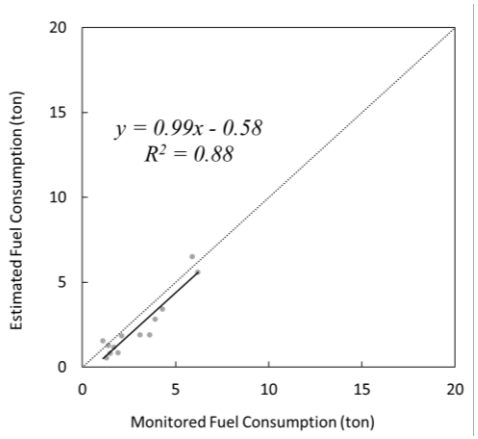
Hotelling mode



Arrival mode

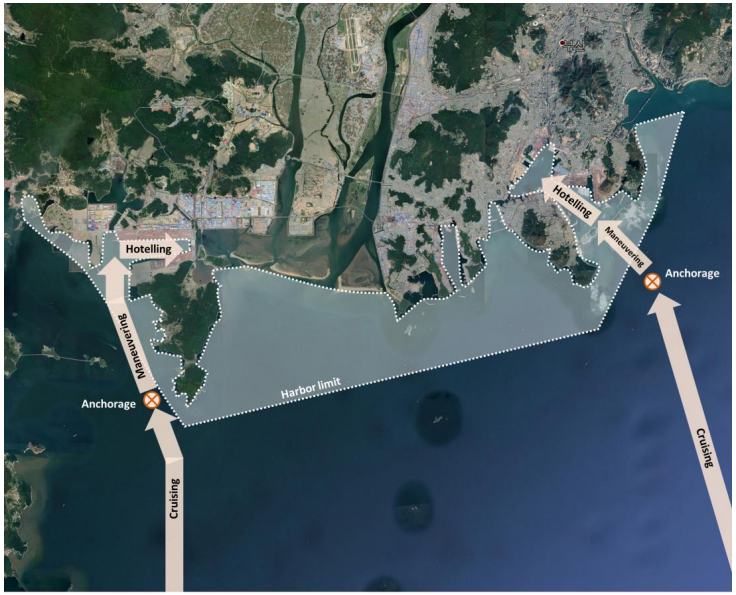


Departure mode

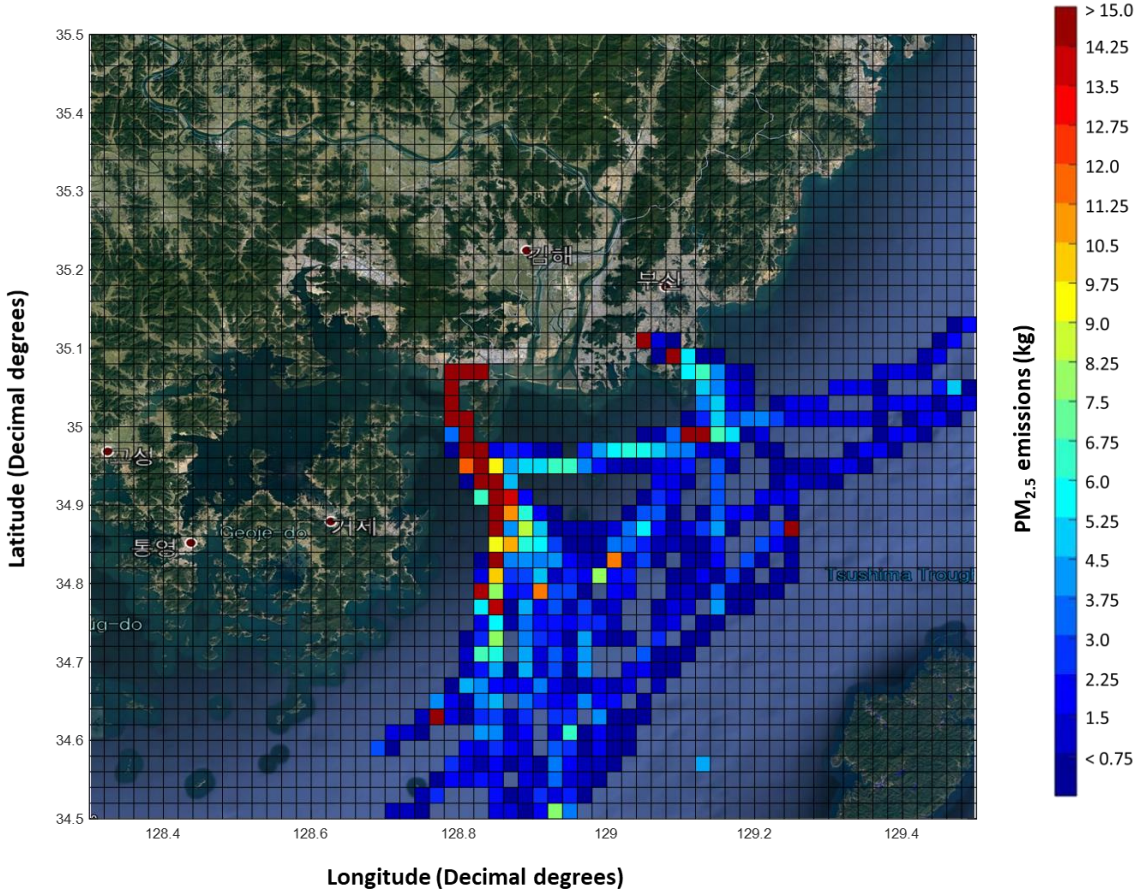


Ⅲ. RESULT AND DISCUSSION

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



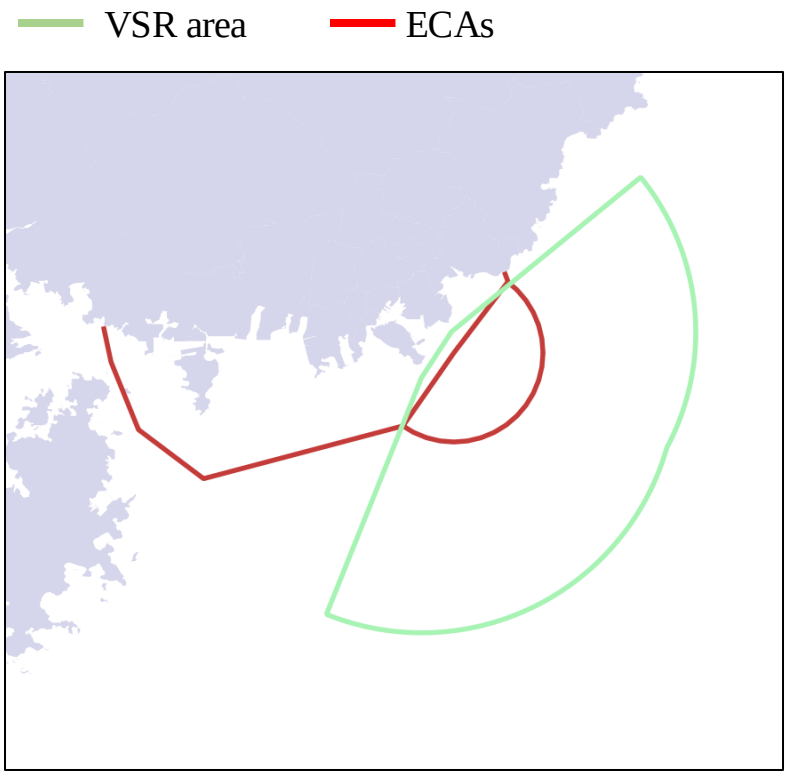
(a) General operation modes in Busan port area



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

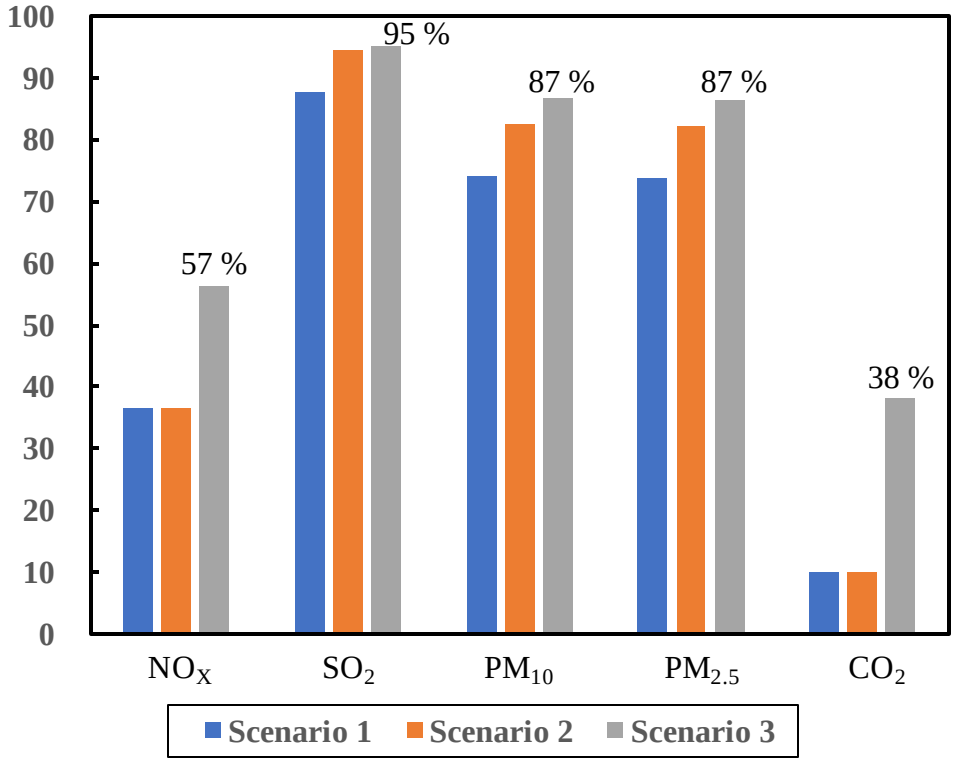
Scenario for reduction policies of ship emissions

- **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

▪ Reduction potential of ship emission regulation by scenario



Scenario	Ship emissions (ton)				
	NOx	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

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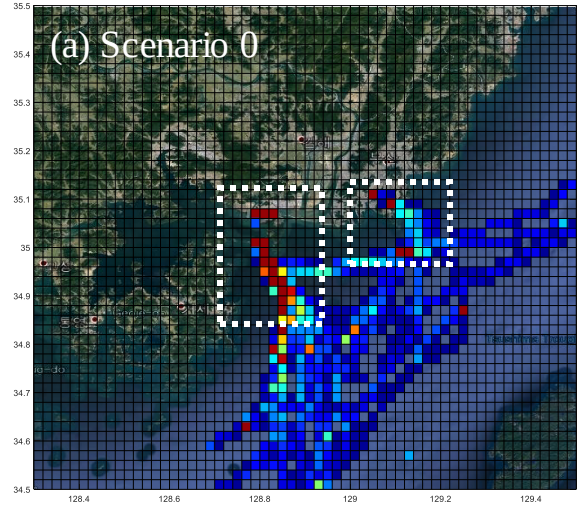
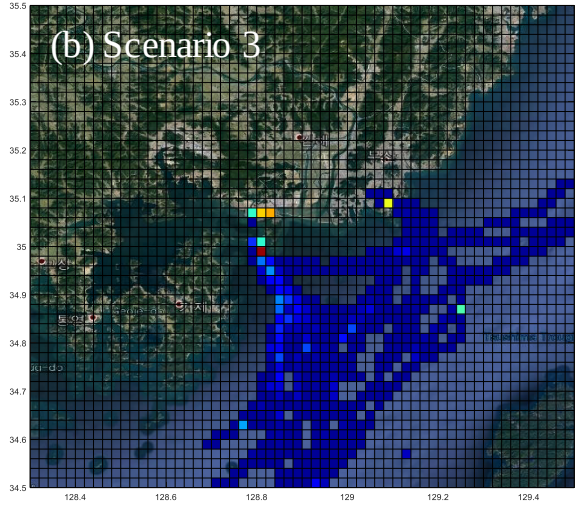
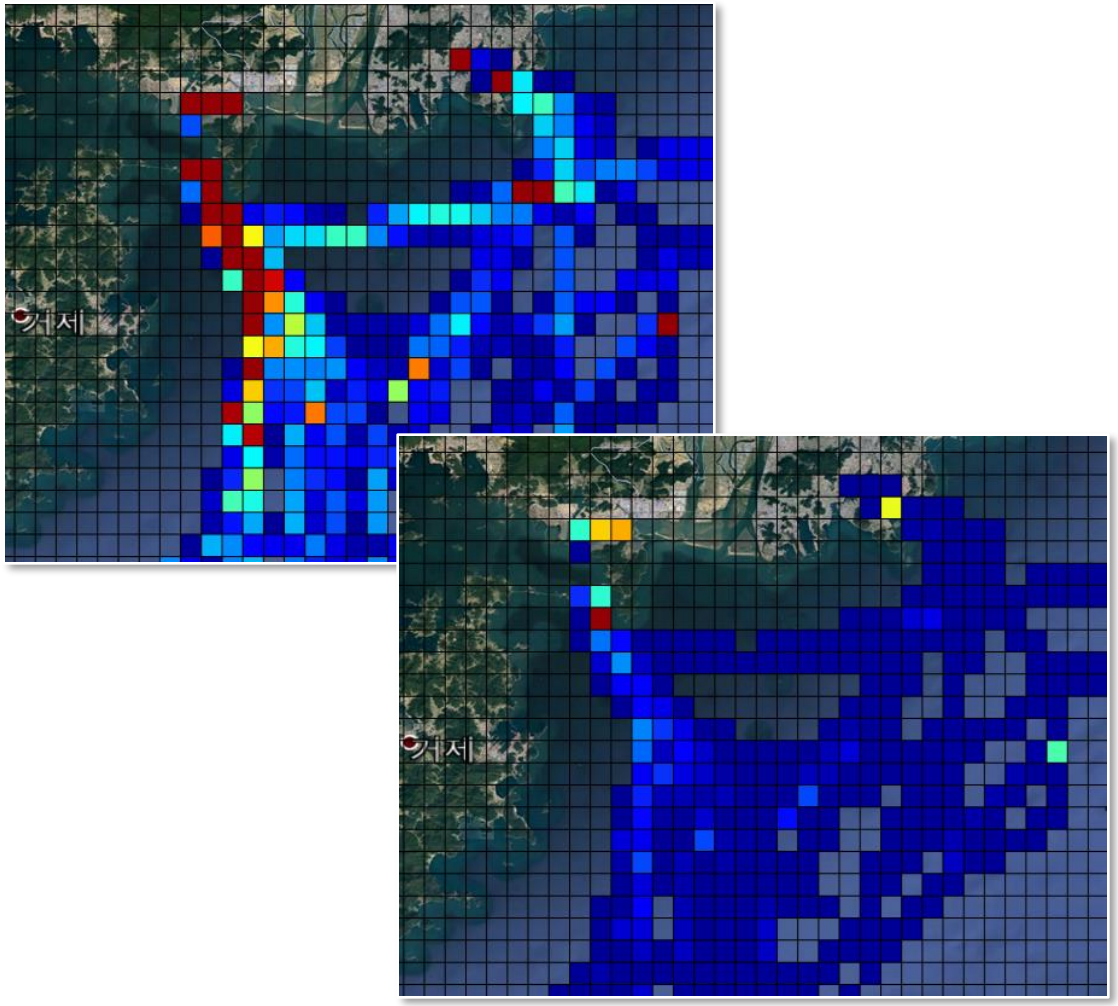
- High-resolution map of ship emission by scenario in Busan







IV. CONCLUSION

Objectives	• 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	▪ 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	▪ 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**

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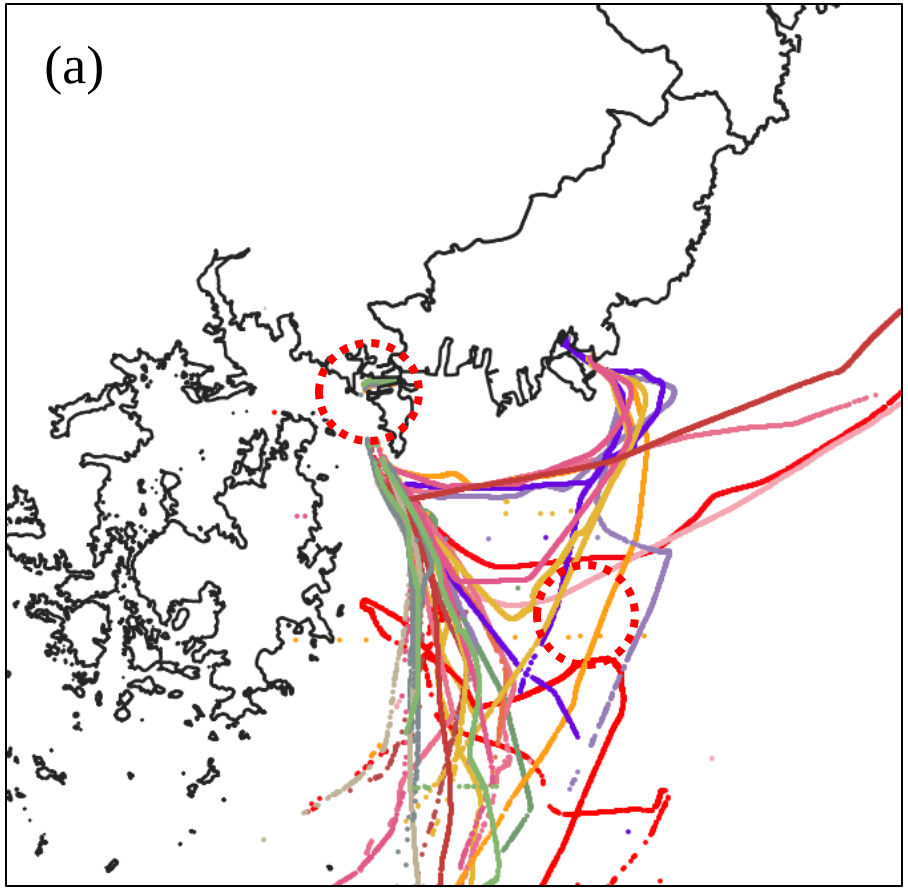
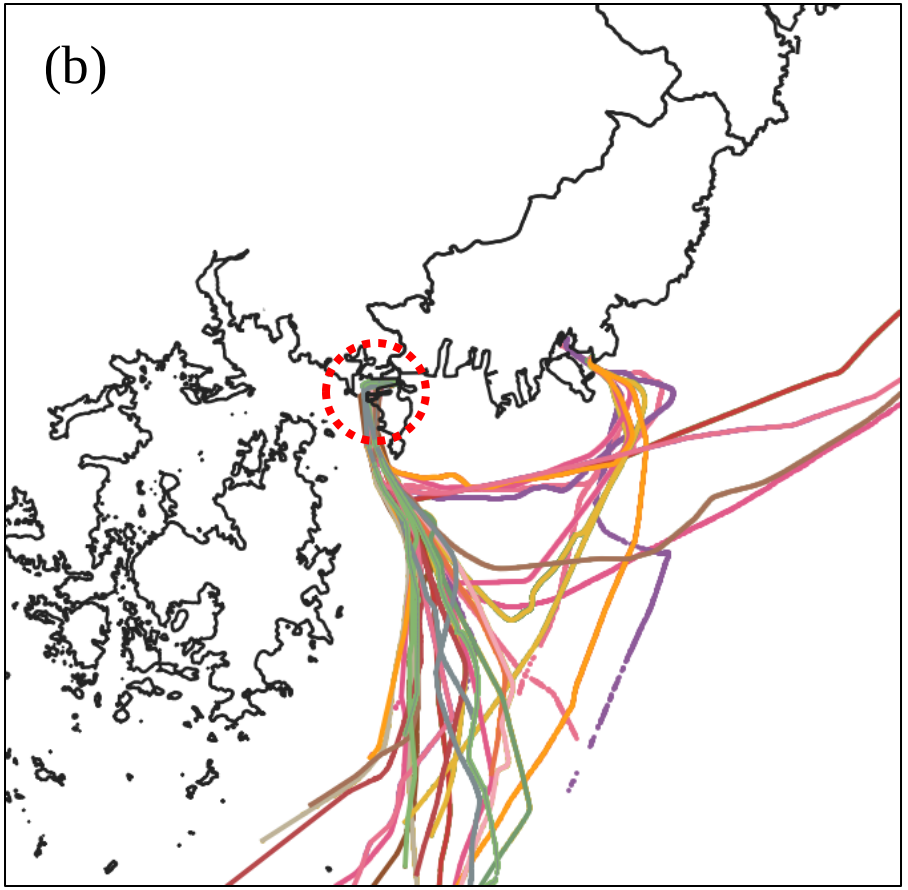
2.4 AIS activity-based ship emission estimation methodology

Preprocess of Automatic Identification System (AIS)

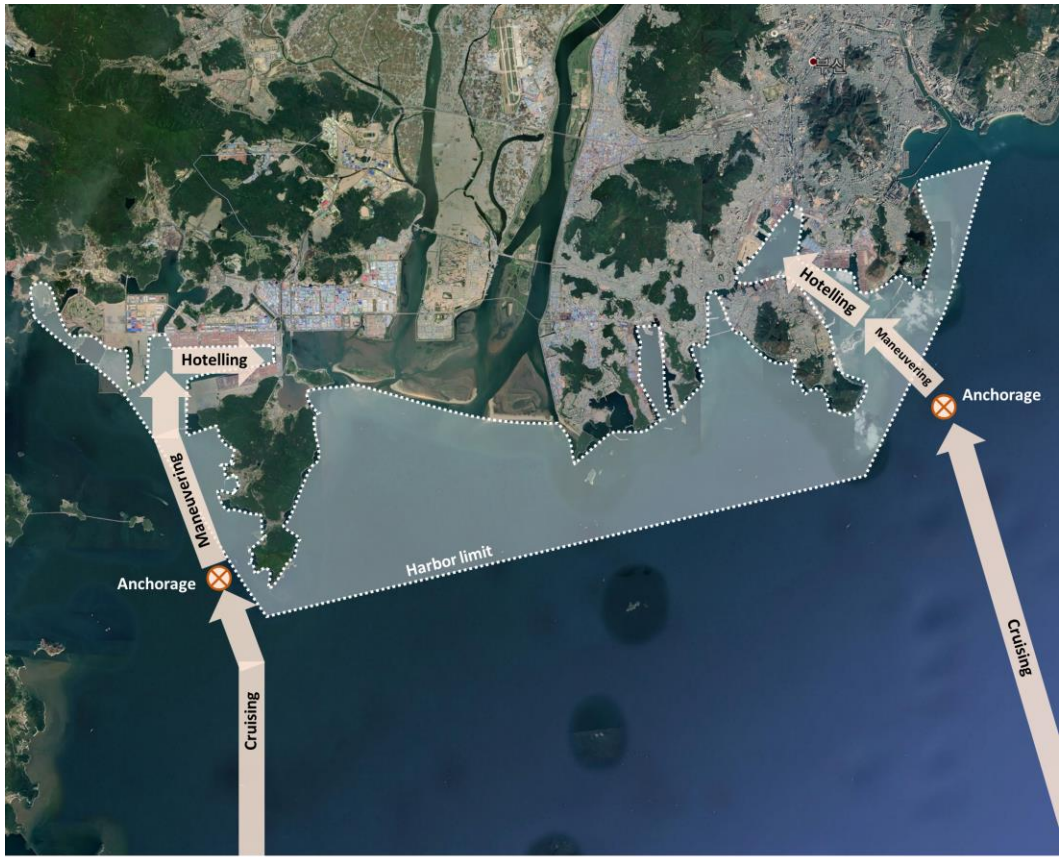
- Remove the error of location coordinate from GPS
- Interpolate linearly missing data



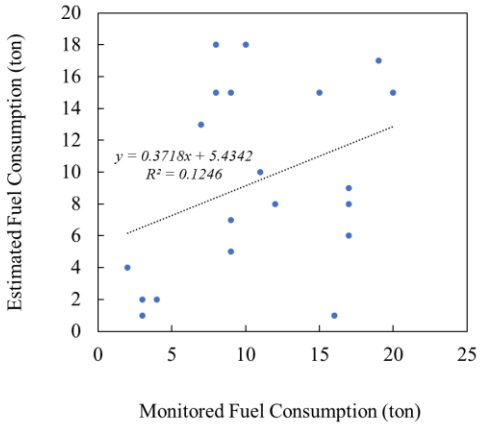


2.4 Validation analysis of AIS-based estimation methodology

- Vessel's operation mode



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



Example

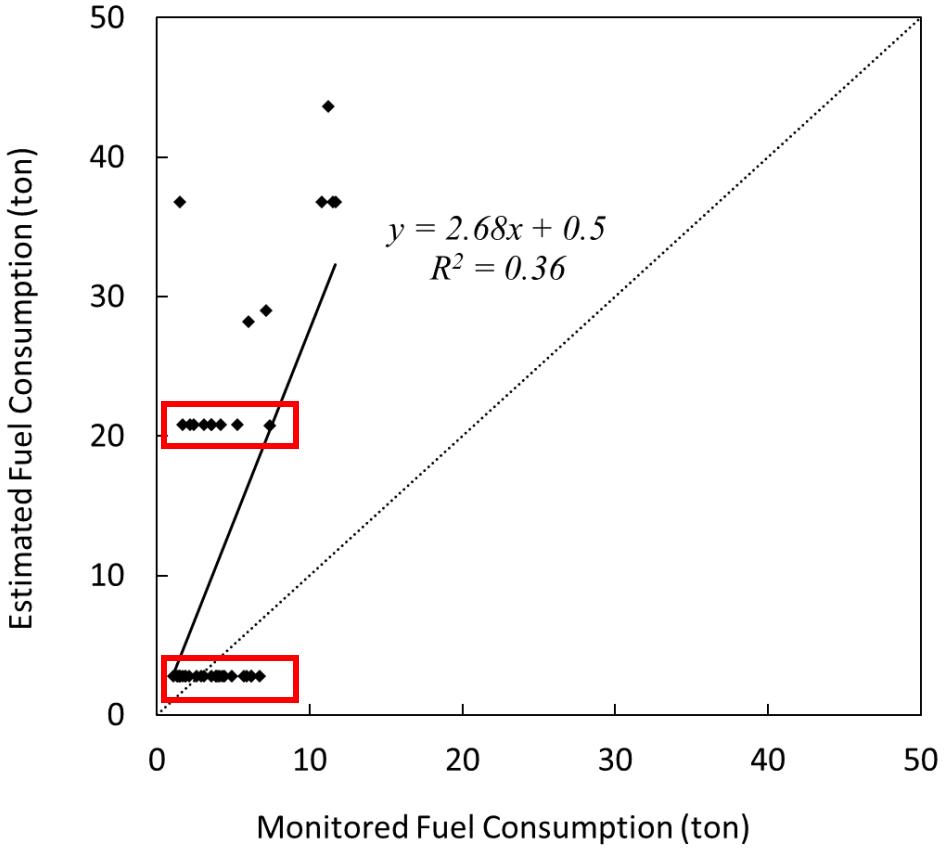
Slope : 0.37

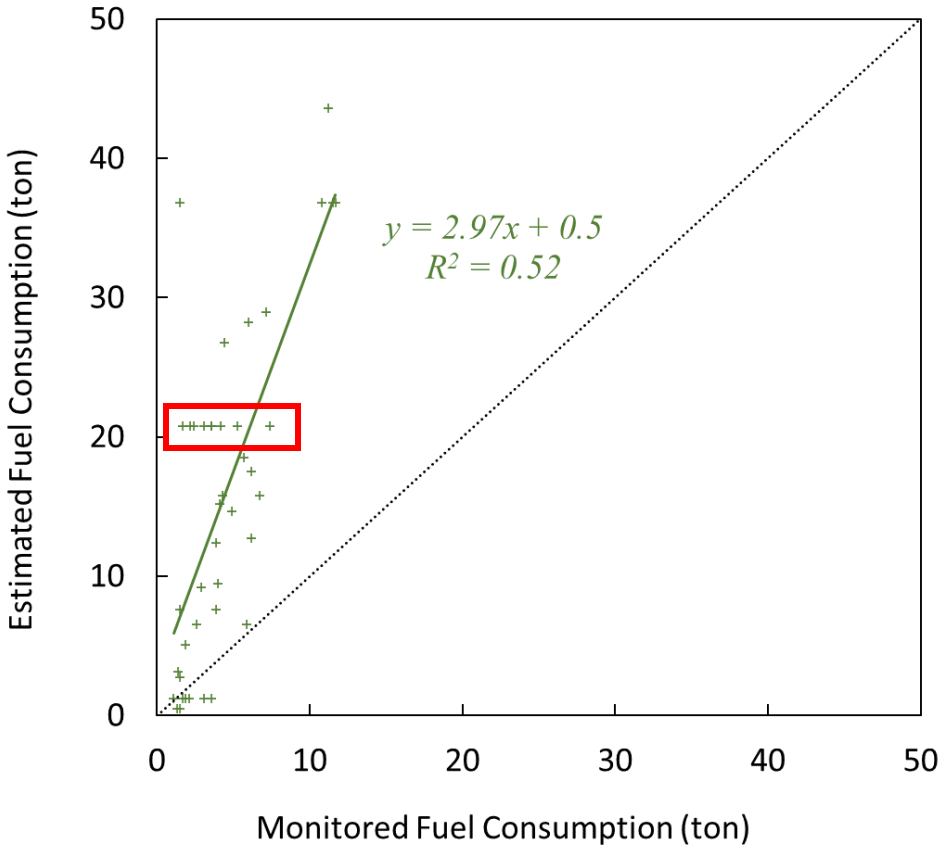
Coefficient of determination (R^2) : 0.12

- 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*)

<table>
<tr><th>Operation Phase</th><th>Low resolution PORT-MIS DB
Method A</th><th>High resolution PORT-MIS DB
Method B</th></tr>
<tr><td>Berth</td><td colspan="2">Fuel Consumption(ton) = N × SFOC (ton/day) × 0.79 (day/N) × 0.2
* 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)
* 0.79 : Average number of Berthing day (day/N)
(Ref: Result of sample research of 560 vessels arrival Ulsan port in January and December 2001)
* 0.2 : Assume 20% output at berth relative to maximum power (Loading Factor)
(Ref: EEA(1999), EMEP/CORINAIR Emission Inventory Guidebook-1999)</td></tr>
<tr><td>Maneuvering</td><td rowspan="2">Fuel Consumption(kL) = N × Cruise Distance(km) ÷ Fuel Economy(km/kL)
* N : Number of Ship calling in the Port
* Cruise Distance : 35km of sea breeze impact in batch
* Fuel Economic : Fuel economy data by Gross tonnage
(Ref: Korea Energy Economics Institute)</td><td>Fuel Consumption(kL) = N × Pilotage Distance(km) ÷ Fuel Economy(km/kL)
* Pilotage Distance : pilotage distance by port
* Fuel Economic : Fuel economy data by Gross tonnage
(Ref: Korea Energy Economics Institute)</td></tr>
<tr><td>Cruising</td><td>Fuel Consumption(ton) = Engine Power(kW) × SFOC (g/kWh) × 0.8 × HRS(h) × 10^{-6}
* SFOC : Specific Fuel Oil Consumption by engine power
(Ref: EMEP/CORINAIR Emission Inventory Guidebook-2009)
* 0.8 : Assume 80% output at berth relative to rated power
(Ref: EMEP/CORINAIR Emission Inventory Guidebook-2009)
* HRS : Record of Arrival/Departure in PORT-MIS</td></tr>
</table>

(Ref: National Air Pollutants Emission Service)

❖ PAQman-Watcher system

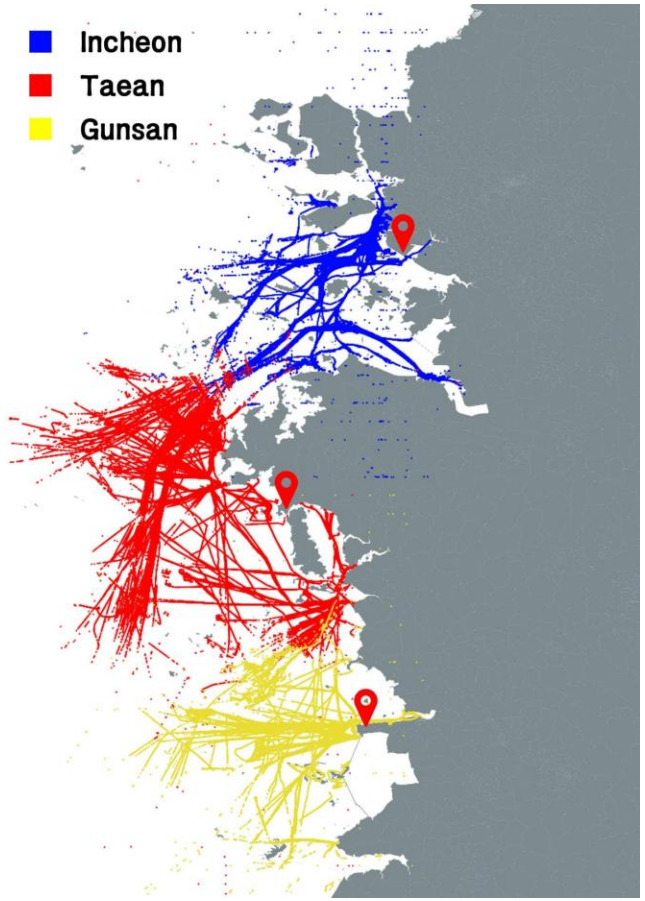
Stationary PAQman-Watcher (Rack mount)

Mobile PAQman-Watcher (Pelican case)

Portable PAQman-Watcher (Pelican case)

AIS ship activity data

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



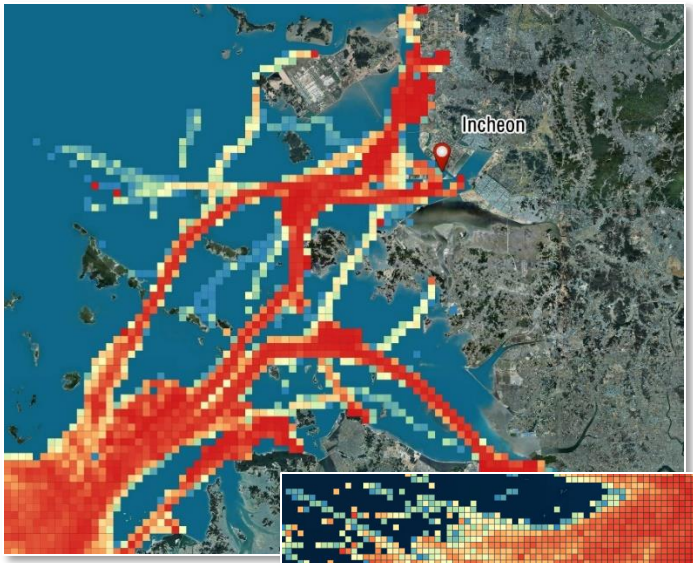
Vessel 'XXXXX' AIS & Specification variables

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

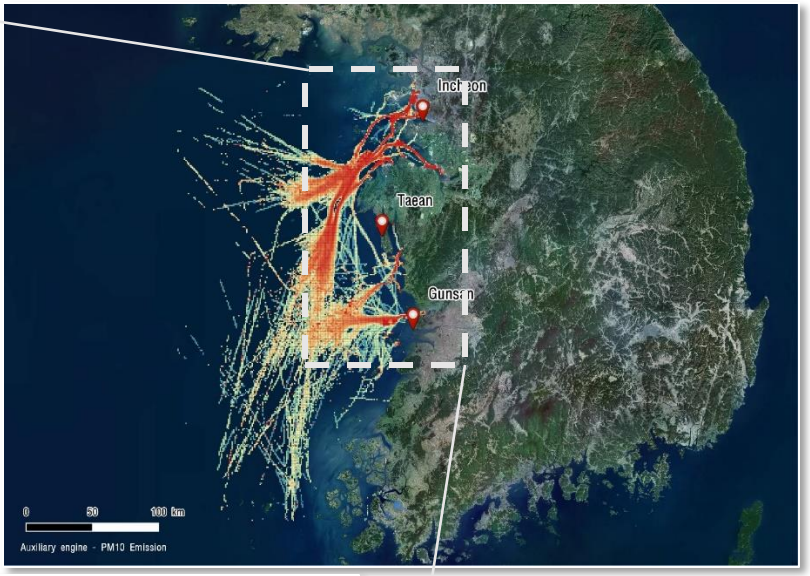
Vessel Specification Variable	Example
Ship Name	xxxxxx
Ship Type	Container ship
Gross Tonnage *(unit: ton)*	18,658
Main Engine Power *(unit: kW)*	11,720
Auxiliary Engine Power *(unit: kW)*	3,660

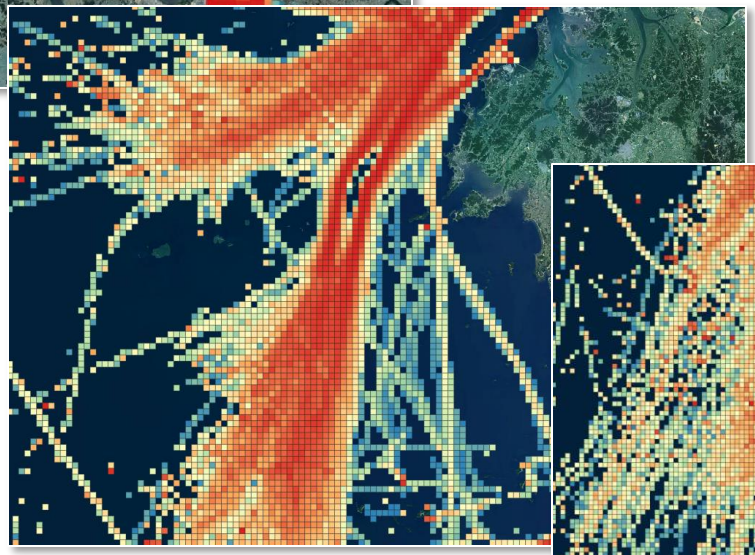
APPENDIX

Ship air emission inventory using PAQman

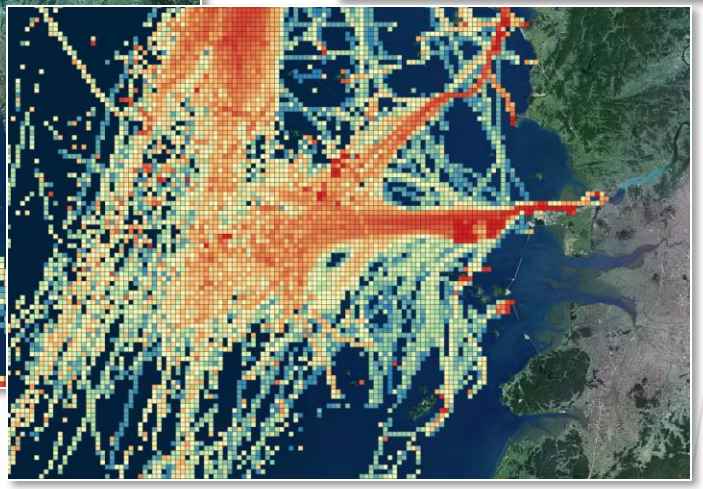


Ship $PM_{2.5}$ emission map in Incheon





Ship $PM_{2.5}$ emission map in Taean



Ship $PM_{2.5}$ emission map in Gunsan