

DISPERSION ESTIMATION OF SHIP GAS EMISSION USING LAGRANGIAN PARTICLE DISPERSION MODEL (LPDM) BASED ON AUTOMATIC IDENTIFICATION SYSTEM (AIS): A CASE STUDY OF MADURA STRAIT

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ABSTRACT

Global warming has a significant impact in last 10 years. Rising sea surface and increasing temperature are impacts of the global warming. International Maritime Organization (IMO) states that CO₂ ship gas emission accounts for approximately 3,1% of annual global CO₂. Madura strait is one of the busiest ship traffics in Indonesia. The strategic location located between two islands, Java island and Madura island, is inevitably affected by the ship gas emission. Nitrogen oxide (NO_x), carbon monoxide (CO), sulfur oxide (SO_x), particular matter (PM_{2,5}) and carbon dioxide (CO₂) are several types of harmful ship gas emission to the mankind. AIS data combined with Puget Method are used to estimate the ship gas emission. The ship gas emission dispersion estimation is using Lagrangian Particle Dispersion Model (LPDM). The study shows that 845,23 kg total of NO_x accounts. Total of CO accounts 67,35 kg. Total of SO₂ accounts 729,18 kg. Total of PM_{2,5} accounts 50,37 kg. The most estimated ship gas emission concentration located at latitude 7°12'53.09"S longitude 112°43'48.40"E which is sub-district Pabean Cantikan. The concentration of NO_x, CO, SO₂, PM_{2,5} and CO₂ are 9,6, E+02 µg/m³, 4,67, E+01 µg/m³ 4,26, E+02 µg/m³, 2,98, E+01 µg/m³ and 2,55, E+04 µg/m³.

Keywords: AIS, Puget Method, Lagrangian Particle Dispersion Model

INTRODUCTION

Emitted gases produced by ship's main engine and auxiliary engine have been considered as contributor in global warming issues. Beside global warming, environmental and health problem also caused by the emitted gasses. The emitted gasses components are nitrogen oxide (NO_x), carbon monoxide (CO), sulfur oxide (SO_x), particular matter (PM_{2,5}) and carbon dioxide (CO₂). For the year 2007, total ship emission was approximately 1.100 million tones CO₂. For the year 2012 938 million tones CO₂ produced by international and national shipping activities. For the period 2007-2012, on average, shipping accounted for approximately 3,1% of annual global CO₂ (IMO, 2015).

Madura Strait located between two islands, Java and Madura, is one of the busiest ship traffic in Indonesia. Many types of ship sailing along Madura strait, such as container carrier, bulk carrier, general cargo, tanker, supply vessel, cement carrier, passenger ship, warship, tug boat, etc. In 2005, more than 15,000 ships sailing in Madura strait. The number increase to at least 30,000 ships in 2010 (Kompas, 2011).

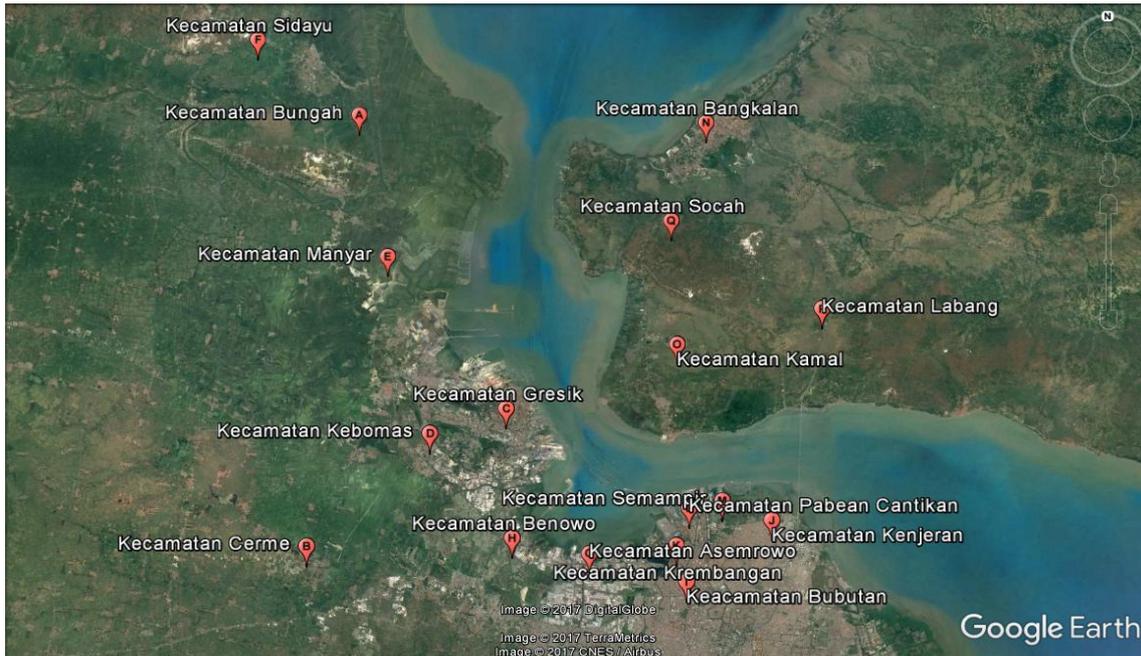


Figure 1. Madura Strait.

In 2050, container carrier 12,000-14,500 TEUs distribution number will increase into 9% which is only 2% in 2012. Liquefied gas carrier 20,000-199,999 m³ distribution number emitted gasses components are nitrogen oxide (NO_x), carbon monoxide (CO), sulfur will increase from 29% in 2012 to 66% in 2050. The distribution number other types of ship, such as bulk carrier 10,000-19,999 dwt, will increase 9% to 40% in 2050 (IMO, 2015).

This paper is using Automatic Identification System (AIS) combined with Puget Method to estimate the emission gasses produced by the ships. AIS data is used to identify the ship data such as dynamic data (latitude, longitude, time, speed over ground, course, etc.) and static data (MMSI, vessel name, ship type, etc.). Puget method is a method to calculate the number of emitted components. The input needed are time, position of the ship (latitude and longitude) and speed over ground from dynamic data.

Lagrangian Particle Dispersion Model (LPDM) was used to estimate the emission gasses distribution along the coastal area of Madura Strait. This method developed to estimate the concentration and deposition of ¹³¹I and ¹³⁷Cs released from the Fukushima nuclear power plant (Soon et al, 2016).

EXPERIMENTAL SET UP

There are several steps to calculate emission gasses produced by ships. As explained before, this paper is using Puget Method to calculate the amounts of emitted components. Puget Method developed by the Puget Sound Maritime Air Forum, a voluntary association of private and public maritime organization ports, air agencies, environmental, public health advocacy groups and the other parties with operational or regulatory responsibilities related to the maritime industry (Starcrest Consulting Group, 2012).

The data inventory was gathered for the following six major source categories associated with marine sectors such as Ocean-going Vessel (OGV), harbor vessels, cargo handling equipment, off-terminal heavy-duty trucks, fleet vehicles and locomotive operations. From the six-major sources above, this paper was using OGV equation to calculate the amounts of emitted components.

Emissions are calculated as a vessel power, where expressed in kilowatt-hour, multiplied by an emission factor, where expressed in terms of grams per kilowatt-hour. The emission is calculated using equation (1).

$$E = Energy \times EF \times FCF \quad (1)$$

where:

E = emission from the engine(s)

Energy = energy demand of the engine(s), in kWh

EF = emission factor, in g/kWh

FCF = fuel correction factor

Table 1. Emission factor for main engine (g/kWh)

Engine	Model Year	NO _x	CO	SO ₂	PM _{2,5}	CO ₂
Slow Speed Diesel	≤ 1999	18,1	1,4	10,5	1,2	620
Medium Speed Diesel	≤ 1999	14,0	1,1	11,5	1,2	683
Slow Speed Diesel	2000-2010	17,0	1,4	10,5	1,2	620
Medium Speed Diesel	2000-2010	13,0	1,1	11,5	1,2	683
Slow Speed Diesel	2011-2015	14,4	1,4	10,5	1,2	620
Medium Speed Diesel	2011-2015	10,5	1,1	11,5	1,2	683
Gas Turbine	All	6,1	0,2	16,5	0,04	970
Steamship	All	2,1	0,2	16,5	0,6	970

Table 2. Auxiliary engine emission factor (g/kWh)

Engine	Model Year	NO _x	CO	SO ₂	PM _{2,5}	CO ₂
Medium Speed Engine	≤ 1999	14,7	1,1	12,3	0,8	683
Medium Speed Engine	2000-2010	13,0	1,1	12,3	0,8	683
Medium Speed Engine	2011-2015	10,5	1,1	12,3	0,8	683

Emission factors for main engine using residual fuel, with an average 2,7% sulfur content, are listed in **Table 1**. The emission factors divide into three kinds of engine such as diesel, gas turbine and stream ship. Diesel engine has two types, slow speed, having maximum engine speeds less than 130 revolutions per minute (rpm) and medium speed, having maximum engine speeds over 130 rpm and typically greater than 400 rpm. The diesel engine emission factor also divides by 3 models. The first model ≤ 1999, the second model between 2000-2010 and the third model between 2011-2015. Emission factor for auxiliary

engine using residual fuel are listed in **Table 2**. All type of auxiliary engine calculated by the Puget method is medium speed engine. The auxiliary engine divides into three models based on its year.

Table 3. Fuel correction factor (g/kWh)

Fuel Used	NO _x	CO	SO ₂	PM _{2.5}	CO ₂
HFO (2.7 % S)	1	1	1	1	1
HFO (1.5 % S)	1	1	0.555	0.82	1
MGO (0.5 % S)	0.94	1	0.185	0.25	1
MDO (1.5 % S)	0.94	1	0.555	0.47	1
MGO (0.1 % S)	0.94	1	0.037	0.17	1
MGO (0.3 % S)	0.94	1	0.111	0.21	1
MGO (0.4 % S)	0.94	1	0.148	0.23	1

Fuel correction factors are used to calculate emission for variations in fuel parameters between several different types of fuel. The fuel correction factors are listed in **Table 3**.

Energy is calculated as a function of maximum continuous rated engine power multiplied by the load factor and the duration of activity. The energy calculated using equation (2).

$$Energy = MCR \times LF \times A \quad (2)$$

where:

MCR = maximum continuous rated engine power, in kW

LF = load factor

A = activity, in hours

Load factor, which in percent, is a ratio of vessel's main engine power or auxiliary engine power output at a speed to the vessel's MCR power. The load factor calculated using equation (3).

$$LF = (Speed_{Actual} / Speed_{Maximum})^3 \quad (3)$$

where:

Speed_{Actual} = ship's actual speed, in knots

Speed_{Maximum} = ship's maximum speed, in knots

Activity estimated by dividing the distance traveled by the ship actual speed. The activity calculated using equation (4).

$$A = D / Speed_{Actual} \quad (4)$$

where:

D = distance, in nautical miles

Speed_{Actual} = ship's actual speed, in knots

LPDM is a method to estimate the emission dispersion. Each particle follows a random path around the mean wind speed. To that effect, the trajectory of each particle is divided into a large number of step, each consisting of a deterministic sub step, and a random sub step representing a change of the wind speed deviation. Because the wind speed deviation is not constant, the random sub steps can be used to predict the concentrations of the pollutant. The advantages of lagrangian particle model over the most commonly used model, plume and puff models, at large distances from the source can accurately described (Walter, 2004).

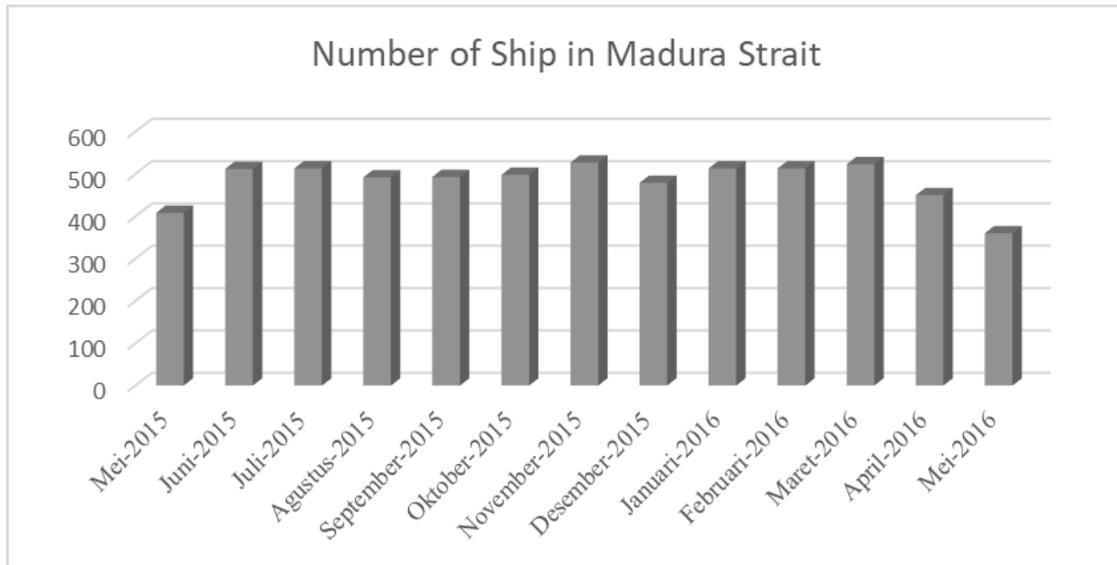


Figure 2. Number of ship in Madura Strait.

A lagrangian particle with a mass of Q_{ke} positioned at (x_k, y_k, z_k) produces near surface concentration (height of z) of $\sigma_{kx}, \sigma_{ky}, \sigma_{kz}$ are standards deviation, calculated using equation below (EnviroComp Consulting inc., 2001).

$$C_k(x, y, z) = \frac{Q_{ke} \frac{-0,693\tau}{\tau}}{(\sqrt{2\pi})^3 \sigma_{kx} \sigma_{ky} \sigma_{kz}} \exp \left[-\frac{(x_k - x)^2}{2\sigma_{kx}^2} - \frac{(y_k - y)^2}{2\sigma_{ky}^2} - \frac{(z_k - z)^2}{2\sigma_{kz}^2} \right] \quad (5)$$

where:

Q_{ke} = emission produced, in gram/hours

x, y, z = sampling position

τ = half-life time of emission, in minutes

$$\sigma_{kx} = 2 \times u \exp \left(-\frac{3fz}{u} \right) \quad (6)$$

$$\sigma_{ky} = \sigma_{kz} = 1,3 \times u \exp \left(-\frac{2fz}{u} \right) \quad (7)$$

$$f = 2 \Omega \sin \phi \quad (8)$$

where:

- C = constant, between 0,15 and 0,25
u = wind velocity, in m/s
 Ω = earth's rotation, which is $7,29 \times 10^{-5} \text{ s}^{-1}$
 Φ = latitude

Table 4. Ship emission estimation (kg)

Ship Type	NO _x	CO	SO	PM _{2,5}	CO ₂
Bulk Carrier	77,12	6,33	70,81	4,61	3931,73
Cement Carrier	55,77	4,27	46,27	3,83	2650,36
Container	217,65	17,46	185,75	12,53	10640,82
General Cargo	215,93	17,10	177,99	13,41	10031,27
Landing Craft	65,32	5,36	59,98	3,90	3330,87
Passenger	14,85	1,25	13,99	0,91	776,80
Supply Vessel	28,17	2,38	25,85	2,13	1480,02
Tanker	207,89	16,06	179,60	11,68	9973,03
Total	882,70	70,22	760,25	53,00	42814,90

RESULTS AND DISCUSSION

The paper was using the data of Mei 2016, which was the newest AIS data. From the data, there were 360 ships sailing in Madura strait. And then the choose the densest traffic which was the 1st May 2016 at 17.00–18.00 WIB. The estimation of ship emission produced in 1st May 2016 at 17.00-18.00 as described in **Table 4**. This paper only calculates NO_x, CO, SO_x, PM_{2,5} and CO₂. The biggest number of emission was produced by the container carrier which produced 217,65 kg of NO_x, 17,46 kg of CO, 185,75 kg of SO_x, 12,53 kg of PM_{2,5} and 10640,82 kg of CO₂.

In the second place was general cargo ship which produced 215,93 kg of NO_x, 17,10 kg of carbon monoxide (CO), 177,99 kg of SO_x, 13,41 kg of PM_{2,5} and 10031,27 kg of CO₂.

In the third place was bulk carrier ship which produced 77,12 kg of NO_x, 6,33 kg of carbon monoxide (CO), 70,81 kg of SO_x, 4,61 kg of PM_{2,5} and 3931,73 kg of CO₂.

The total emission produced by all types of ship were 882,70 kg of NO_x, 70,22 kg of CO, 760,25 kg of SO_x, 53 kg of PM_{2,5} and 42814,90 kg of CO₂.

The calculated emission then simulated using Hysplit. There are several data needed such as the meteorological data (wind speed in m/s, wind direction in degrees and the longitude and latitude position), emission rate in kg/hour, number of emission source(s) and total runtime of the simulation.

The meteorological data obtained from the Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) Maritime, Surabaya. The meteorological data in 1st May 2016 at 17.00-18.00 was 3,7 m/s to the 256,88°. With the center of the wind source at longitude -7.15° and latitude 112,66°.

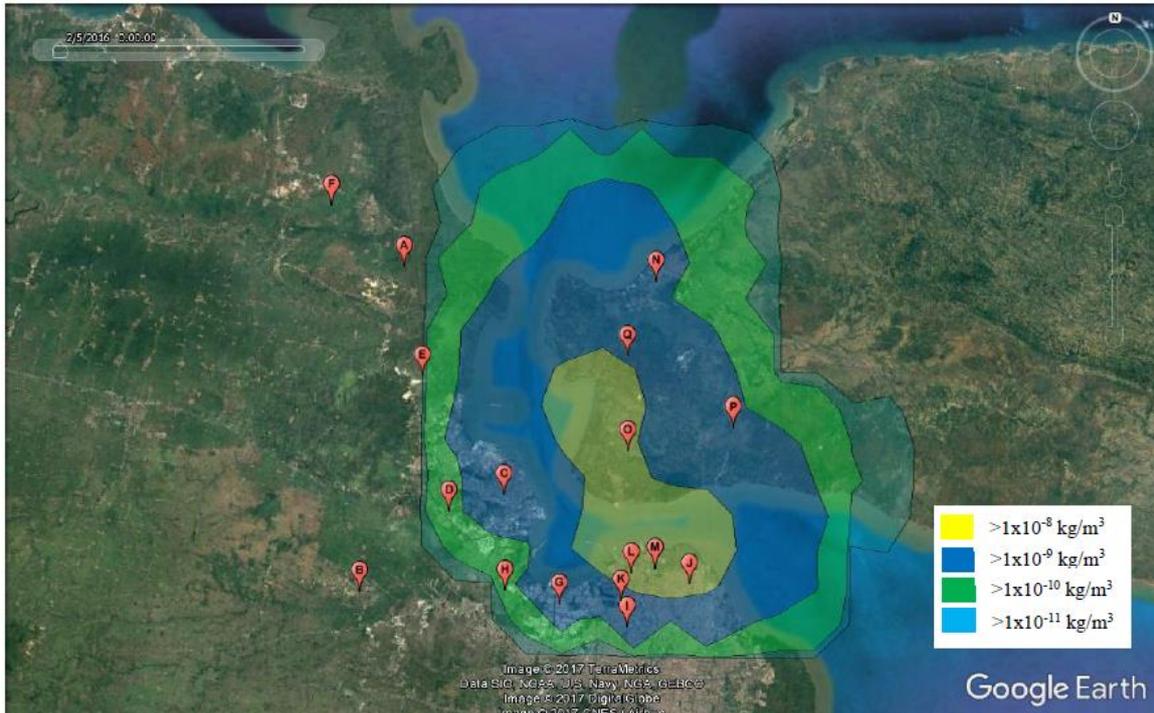


Figure 3. Distribution of NO_x emission using Hysplit

Emission concentration simulation using Hysplit shows in **Figure 3**. **Figure 3** shows 4 areas divided by number of emission concentrate. There is the yellow area, the blue area, the green area and the light blue area. The yellow area shows that the concentration of NO_x in the area $>1 \times 10^{-8} \text{ kg/m}^3$. The blue area shows that the concentration of NO_x in the area $>1 \times 10^{-9} \text{ kg/m}^3$. The green area shows that the concentration of NO_x in the area $>1 \times 10^{-10} \text{ kg/m}^3$. The light blue area shows that the concentration of NO_x in the area $>1 \times 10^{-11} \text{ kg/m}^3$.

The sampling sites in yellow area with NO_x concentration $> 1 \times 10^{-8} \text{ kg/m}^3$ are:

- Sub-district Kamal
- Sub-district Pabean Cantikan
- Sub-district Semampir
- Sub-district Kenjeran
- Sub-district Krembangan

The sampling sites in blue area with NO_x concentration $> 1 \times 10^{-9} \text{ kg/m}^3$ are:

- Sub-district Gresik
- Sub-district Asemworo
- Sub-district Bubutan
- Sub-district Bangkalan
- Sub-district Labang
- Sub-district Socah

The sampling sites in green area with NO_x concentration $> 1 \times 10^{-10} \text{ kg/m}^3$ are:

- Sub-district Kebomas
- Sub-district Benowo

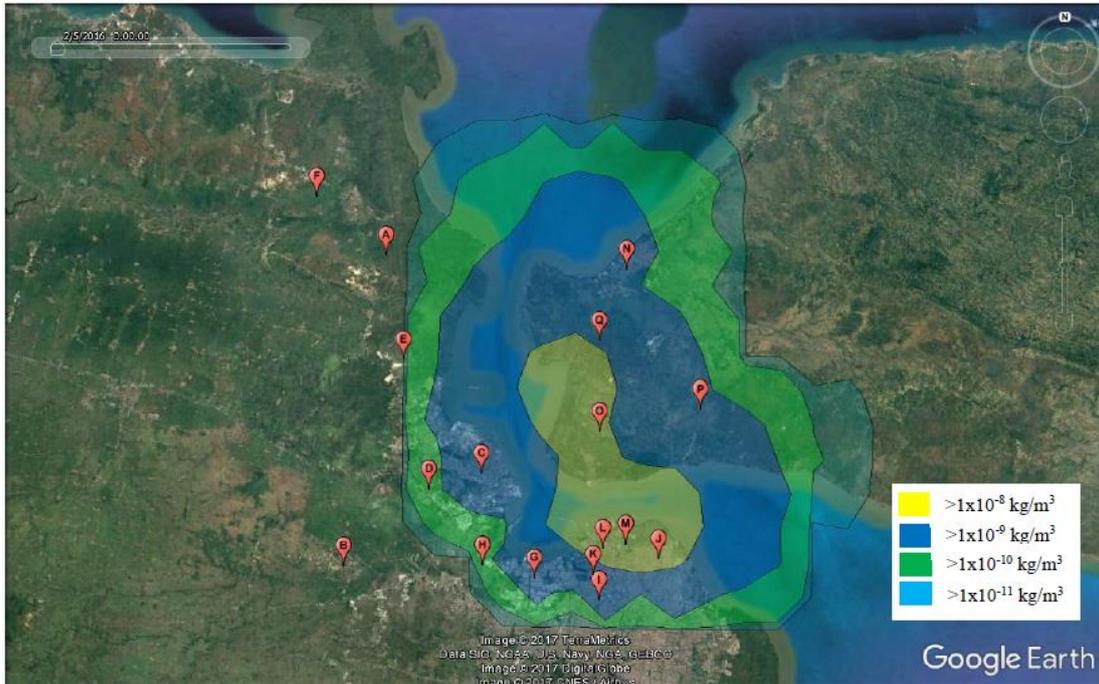


Figure 4. Distribution of CO emission using Hysplit

CO emission concentration simulation using Hysplit also divided 4 areas. In **Figure 4**, there are the yellow area, the blue area, the green area and the light blue area. The yellow area shows that the concentration of CO in the area $>1 \times 10^{-9} \text{ kg/m}^3$. The blue area shows that the concentration of CO in the area $>1 \times 10^{-10} \text{ kg/m}^3$. The green area shows that the concentration of CO in the area $>1 \times 10^{-11} \text{ kg/m}^3$. The light blue area shows that the concentration of CO in the area $>1 \times 10^{-12} \text{ kg/m}^3$.

The sampling sites in yellow area with CO concentration $> 1 \times 10^{-9} \text{ kg/m}^3$ are:

- Sub-district Pabean Cantikan
- Sub-district Semampir
- Sub-district Kenjeran
- Sub-district Kamal

The sampling sites in blue area with CO concentration $> 1 \times 10^{-10} \text{ kg/m}^3$ are:

- Sub-district Gresik
- Sub-district Asemworo
- Sub-district Bubutan
- Sub-district Krembangan
- Sub-district Bangkalan
- Sub-district Labang
- Sub-district Socah

The sampling sites in green area with CO concentration $> 1 \times 10^{-11} \text{ kg/m}^3$ are:

- Sub-district Kebomas
- Sub-district Benowo

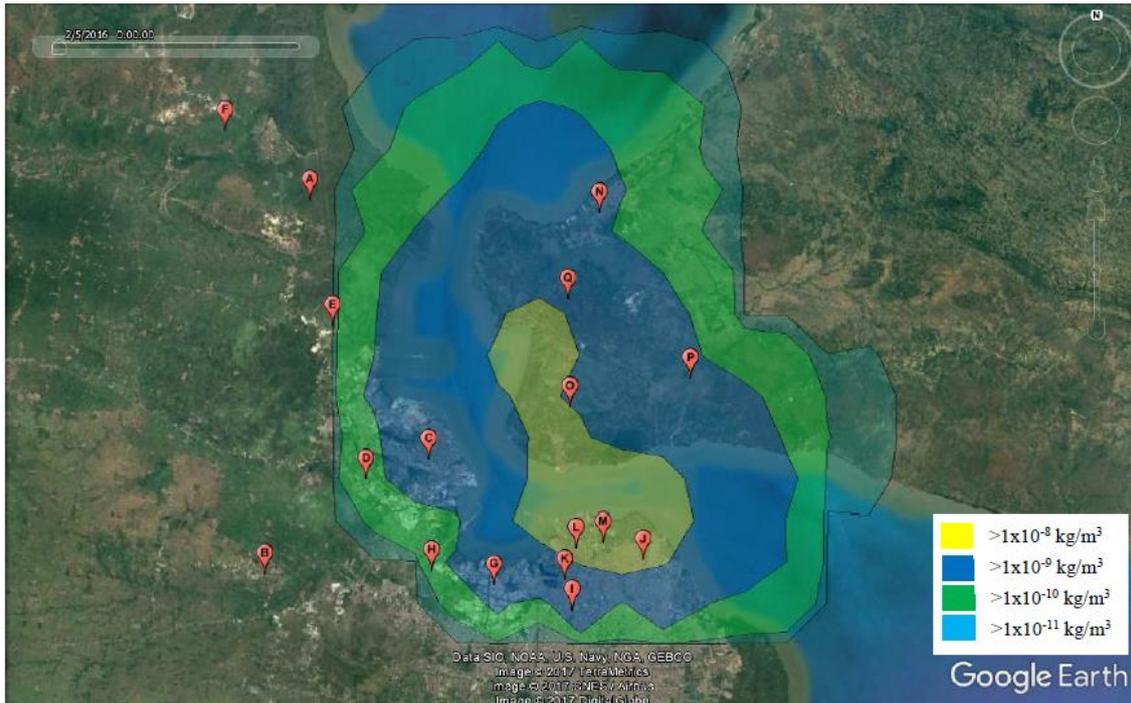


Figure 5. Distribution of SO₂ emission using Hysplit

SO₂ emission concentration simulation using Hysplit also divided 4 areas. In **Figure 5**, there are the yellow area, the blue area, the green area and the light blue area. The yellow area shows that the concentration of SO₂ in the area $>1 \times 10^{-8} \text{ kg/m}^3$. The blue area shows that the concentration of SO₂ in the area $>1 \times 10^{-9} \text{ kg/m}^3$. The green area shows that the concentration of SO₂ in the area $>1 \times 10^{-10} \text{ kg/m}^3$. The light blue area shows that the concentration of SO₂ in the area $>1 \times 10^{-11} \text{ kg/m}^3$.

The sampling sites in yellow area with SO₂ concentration $> 1 \times 10^{-8} \text{ kg/m}^3$ are:

- Sub-district Pabean Cantikan
- Sub-district Semampir
- Sub-district Kenjeran
- Sub-district Kamal

The sampling sites in blue area with SO₂ concentration $> 1 \times 10^{-9} \text{ kg/m}^3$ are:

- Sub-district Gresik
- Sub-district Asemworo
- Sub-district Bubutan
- Sub-district Krembangan
- Sub-district Bangkalan
- Sub-district Labang
- Sub-district Socah

The sampling sites in green area with SO₂ concentration $> 1 \times 10^{-10} \text{ kg/m}^3$ are:

- Sub-district Kebomas
- Sub-district Benowo

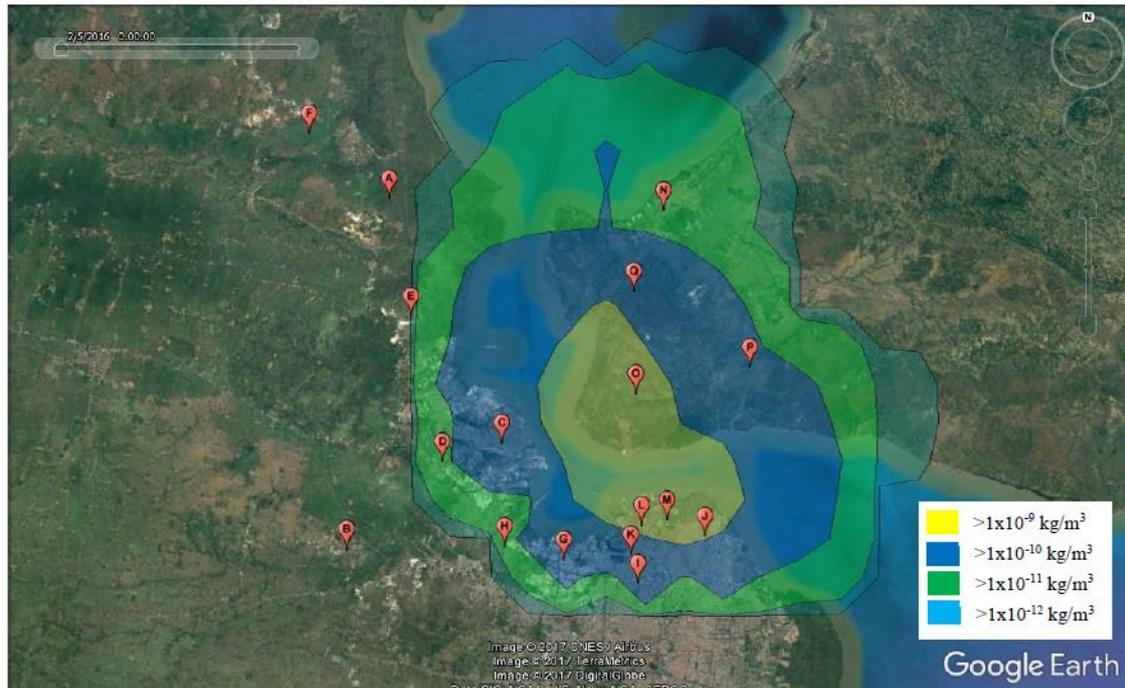


Figure 6. Distribution of PM_{2,5} emission using Hysplit

PM_{2,5} emission concentration simulation using Hysplit also divided 4 areas. In **Figure 6**, there are the yellow area, the blue area, the green area and the light blue area. The yellow area shows that the concentration of PM_{2,5} in the area $>1 \times 10^{-9} \text{ kg/m}^3$. The blue area shows that the concentration of PM_{2,5} in the area $>1 \times 10^{-10} \text{ kg/m}^3$. The green area shows that the concentration of PM_{2,5} in the area $>1 \times 10^{-11} \text{ kg/m}^3$. The light blue area shows that the concentration of SO₂ in the area $>1 \times 10^{-12} \text{ kg/m}^3$.

The sampling sites in yellow area with PM_{2,5} concentrations $> 1 \times 10^{-9} \text{ kg/m}^3$ are:

- Sub-district Pabean Cantikan
- Sub-district Semampir
- Sub-district Kenjeran

The sampling sites in blue area with PM_{2,5} concentrations $> 1 \times 10^{-10} \text{ kg/m}^3$ are:

- Sub-district Gresik
- Sub-district Asemworo
- Sub-district Bubutan
- Sub-district Krembangan
- Sub-district Bangkalan
- Sub-district Kamal
- Sub-district Labang
- Sub-district Socah

The sampling sites in green area with PM_{2,5} concentrations $> 1 \times 10^{-11} \text{ kg/m}^3$ are:

- Sub-district Kebomas
- Sub-district Benowo

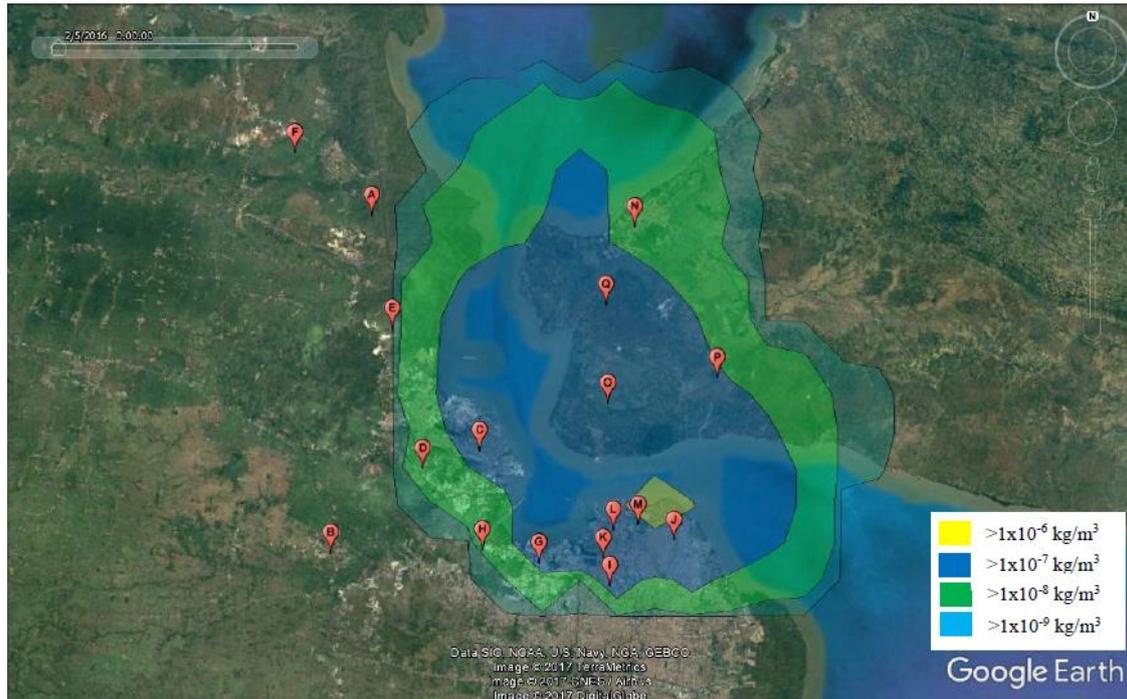


Figure 7. Distribution of CO₂ emission using Hysplit

CO₂ emission concentration simulation using Hysplit also divided 4 areas. In **Figure 7**, there are the yellow area, the blue area, the green area and the light blue area. The yellow area shows that the concentration of CO₂ in the area $>1 \times 10^{-6} \text{ kg/m}^3$. The blue area shows that the concentration of CO₂ in the area $>1 \times 10^{-7} \text{ kg/m}^3$. The green area shows that the concentration of CO₂ in the area $>1 \times 10^{-8} \text{ kg/m}^3$. The light blue area shows that the concentration of CO₂ in the area $>1 \times 10^{-9} \text{ kg/m}^3$.

The sampling sites in yellow area with CO₂ concentration $> 1 \times 10^{-6} \text{ kg/m}^3$ are:

- Sub-district Semampir
- Sub-district Kenjeran
- Sub-district Pabean Cantikan

The sampling sites in blue area with CO₂ concentration $> 1 \times 10^{-7} \text{ kg/m}^3$ are:

- Sub-district Gresik
- Sub-district Asemworo
- Sub-district Bubutan
- Sub-district Krembangan
- Sub-district Kamal
- Sub-district Labang
- Sub-district Socah

The sampling sites in green area with CO₂ concentration $> 1 \times 10^{-8} \text{ kg/m}^3$ are:

- Sub-district Kebomas
- Sub-district Benowo
- Sub-district Bangkalan

Table 5. Ship emission concentration at each sampling sites

	Daerah	NO _x	CO	SO	PM _{2,5}	CO ₂
A	Sub-district Bungah	4,24,E-09	7,06,E-10	6,67,E-09	5,44,E-10	3,83,E-07
B	Sub-district Cerme	1,37,E-17	2,20,E-18	2,07,E-17	1,71,E-18	1,18,E-15
C	Sub-district Gresik	1,55,E+01	1,84,E+00	1,68,E+01	1,32,E+00	9,75,E+02
D	Sub-district Kebomas	5,68,E-02	7,64,E-03	7,00,E-02	5,66,E-03	4,06,E+00
E	Sub-district Manyar	3,08,E-05	4,81,E-06	4,51,E-05	3,66,E-06	2,60,E-03
F	Sub-district Sidayu	1,42,E-25	2,50,E-26	2,38,E-25	1,95,E-26	1,36,E-23
G	Sub-district Asemrowo	8,57,E+01	7,90,E+00	7,30,E+01	5,13,E+00	4,30,E+03
H	Sub-district Benowo	4,96,E+01	5,04,E+00	4,66,E+01	3,53,E+00	2,67,E+03
I	Sub-district Bubutan	4,80,E+02	2,25,E+01	2,09,E+02	1,44,E+01	1,23,E+04
J	Sub-district Kenjeran	1,44,E+01	1,15,E+00	1,13,E+01	7,32,E-01	6,25,E+02
K	Sub-district Krembangan	7,35,E+02	3,75,E+01	3,41,E+02	2,40,E+01	2,05,E+04
L	Sub-district Pabean Cantikan	9,06,E+02	4,67,E+01	4,26,E+02	2,98,E+01	2,55,E+04
M	Sub-district Semampir	2,23,E+02	1,19,E+01	1,17,E+02	7,58,E+00	6,47,E+03
N	Sub-district Bangkalan	1,26,E+00	7,04,E-02	6,93,E-01	4,49,E-02	3,84,E+01
O	Sub-district Kamal	4,94,E+02	2,55,E+01	2,40,E+02	1,63,E+01	1,39,E+04
P	Sub-district Labang	5,20,E-03	4,23,E-04	4,18,E-03	2,70,E-04	2,31,E-01
Q	Sub-district Socah	6,88,E+01	3,84,E+00	3,63,E+01	2,45,E+00	2,10,E+03

LPDM can be calculated manually using equation (5). The result of the calculation shows at **Table 5**. **Table 5** shows us that the biggest ship emission concentration was located at sub-district Pabean Cantikan with concentration of NO_x 9,06x10² µg/m³. The concentration of CO 4,67x10¹ µg/m³. The concentration of SO 4,26x10² µg/m³. The concentration of PM_{2,5} 2,98 x 10¹ µg/m³. The concentration of CO₂ 2,55 x 10⁴ µg/m⁴.

CONCLUSION

This paper demonstrates which the use of AIS in combination of Puget method can be utilized to estimate the emission dispersion produced by the ship. The estimation of emissions in Madura strait on the 1st May 2016 at 17.00-18.00 WIB are 882,70 kg of nitrogen oxide (NO_x), 70,22 kg of carbon monoxide (CO), 760,25 kg of sulfur oxide (SO_x), 53 kg of particular matter (PM_{2,5}) and 42814,90 kg of carbon dioxide (CO₂).

LPDM can be used to simulate the ship emission concentration distribution. From the 17 sampling sites, the most emission concentration was at Sub-district Pabean Cantikan with 9,06, E+02 µg/m³ of nitrogen oxide (NO_x), 4,67, E+01 µg/m³ of carbon monoxide (CO), 4,26, E+02 µg/m³ of sulfur oxide (SO_x), 2,98, E+01 µg/m³ of particular matter (PM_{2,5}) and 2,55, E+04 µg/m³ kg of carbon dioxide (CO₂).

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