Supplementary Materials

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Additional Material and Methods

S.1 Theoretical analysis of impact of thinning on Ships' Air Pollutant Emissions Inventory

If the AIS data is thinned at the time interval of t, the time interval and speed between adjacent messages before thinning are recorded as t_i, v_i respectively. Where $i = 0, 1, 2,..., n$. Then when t_i is approximately equal, the emissions with and without thinning are respectively:

$$E_{before} = \sum_{i=1}^{n}(k \times t_i \times v_i^3) = k \times \sum_{i=1}^{n}(t_i \times v_i^3) \tag{S1}$$

$$E_{after} = k \times t \times v^3 = k \times \sum_{i=1}^{n} t_i \times (\frac{\sum_{i=1}^{n} v_i}{n})^3 \tag{S2}$$

When i =1, $E_{before} \geq E_{after}$

When i =2,

$$E_{before} - E_{after} = k \times [t_1 \times v_1^3 + t_2 \times v_2^3 - (t_1 + t_2)\left(\frac{v_1 - v_2}{2}\right)^3]$$

$$= k \times \frac{3(v_1+v_2)(v_1-v_2)(v_1t_1-v_2t_2)}{4} \tag{S3}$$

When $t_1 \approx t_2$, $E_{before} \geq E_{after}$

Suppose that when n=m-1, $E_{before} \geq E_{after}$, then when n = m:

$$E_{before} = \sum_{i=1}^{m}(t_i \times v_i^3) = \sum_{i=1}^{m-1}(t_i \times v_i^3) + t_m \times v_m^3 \tag{S4}$$

$$E_{after} = (\sum_{i=1}^{m} t_i) \times \left(\frac{\sum_{i=1}^{m} v_i}{m}\right)^3 = (\sum_{i=1}^{m-1} t_i + t_m) \times \left(\frac{(m-1)\sum_{i=1}^{m-1} v_i + v_m(m-1)}{m(m-1)}\right)^3$$

$$= (\sum_{i=1}^{m-1} t_i + t_m) \times \left(\frac{\sum_{i=1}^{m-1} v_i}{m-1} + \frac{v_m}{m} - \frac{\sum_{i=1}^{m-1} v_i}{m(m-1)}\right)^3 = (\sum_{i=1}^{m-1} t_i + t_m) \times \left(\overline{v} + \frac{v_m - \overline{v}}{m}\right)^3$$

$$= (\sum_{i=1}^{m-1} t_i + t_m) \times \left[\overline{v}^3 + 3\overline{v}^2 \frac{v_m - \overline{v}}{m} + 3\overline{v}(\frac{v_m - \overline{v}}{m})^2 + \left(\frac{v_m - \overline{v}}{m}\right)^3\right]$$

$$= \sum_{i=1}^{m-1} t_i \times \overline{v}^3 + (\sum_{i=1}^{m-1} t_i)\left[3\overline{v}^2 \frac{v_m - \overline{v}}{m} + 3\overline{v}(\frac{v_m - \overline{v}}{m})^2 + \left(\frac{v_m - \overline{v}}{m}\right)^3\right] + t_m \times \left(\overline{v} + \frac{v_m - \overline{v}}{m}\right)^3 \tag{S5}$$

Known $\sum_{i=1}^{m-1}(t_i \times v_i^3) \geq \left[\frac{\sum_{i=1}^{m-1} v_i}{(m-1)}\right]^3 \times \sum_{i=1}^{m-1} t_i$

$$E_{before} - E_{after} \geq t_m \times v_m^3 - (\sum_{i=1}^{m-1} t_i)\left[3\overline{v}^2 \frac{v_m - \overline{v}}{m} + 3\overline{v}(\frac{v_m - \overline{v}}{m})^2 + \left(\frac{v_m - \overline{v}}{m}\right)^3\right] - t_m \times \left(\overline{v} + \frac{v_m - \overline{v}}{m}\right)^3 \tag{S6}$$

Because the time interval of AIS raw data is approximately equal, it is assumed that $\frac{\sum_{i=1}^{m-1} t_i}{m-1} = nt_m$. We assume that $v_m = (k+1)\overline{v}$, then $v_m - \overline{v} = k\overline{v}$, and $k \geq -1$

$$\frac{E_{before} - E_{after}}{\overline{v}^2 t_m} \geq (k+1)^3 - n\left(\frac{3}{m}k + \frac{3}{m^2}k^2 + \frac{1}{m^3}k^3\right) - \left(1 + \frac{k}{m}\right)^3$$

$$= k^3 + 3k^2 + 3k + 1 - \frac{n}{m^3}k^3 - 3\frac{n}{m^2}k^2 - 3\frac{n}{m}k - \frac{k^3}{m^3} - 3\frac{k^2}{m^2} - 3\frac{k}{m} - 1$$

$$= k^3 + 3k^2 + 3k - (n+1)((\frac{k}{m})^3 + 3(\frac{k}{m})^2 + 3\frac{k}{m}) \tag{S7}$$

Assume that $f(k) = k^3 + 3k^2 + 3k - (n+1)((\frac{k}{m})^3 + 3(\frac{k}{m})^2 + 3\frac{k}{m})$ (S8)

Then

$$f'(k) = 3k^2 + 6k + 3 - \frac{(n+1)}{m}\left(3\left(\frac{k}{m}\right)^2 + 6\frac{k}{m} + 3\right) = 3(k+1)^2 - 3\frac{(n+1)}{m}\left(\frac{k}{m} + 1\right)^2 \tag{S9}$$

Because the time interval of AIS raw data is approximately equal, so $n \approx m - 1$

When $k \geq 0$,

$$f'(k) = 3(k+1)^2 - 3\left(\frac{k}{m} + 1\right)^2 \geq 0 \tag{S10}$$

When $0 > k \geq -1$,

$$f'(k) = 3(k+1)^2 - 3\left(\frac{k}{m} + 1\right)^2 \leq 0 \tag{S11}$$

According to the formula (8), $f(0) = 0$

So when $n \approx m - 1$, $f(k) \geq 0, k \geq -1$ set up.

In summary $E_{before} \geq E_{after}$, when and only when k=0, i.e., $v_1 = v_2 = \cdots = v_m$. That is, when the ship travels at a constant speed, the equal sign is established. Therefore, the thinning process of AIS data will reduce the results of ships' air pollutant emission inventory.

S.2 Sources of uncertainty

The original AIS data obtained from the Marine Department were reliable. The accuracy of the AIS data was only limited to the accuracy of the AIS receiver and the base stations. Most of the basic ship information was obtained from Lloyd's database, while it is the most used and complete source for the basic ship information. thus, the emission inventory according to the existing AIS data are relatively reliable. The main impact of data thinning

on AIS data includes the speed and the time of the ship sailed at this speed, so various emission factors have little effect on the results. But low load factor of the ship's main engine (LLAM) will be affected after data thinning. This changes in LLAM brings some uncertainty.

Additional Figures

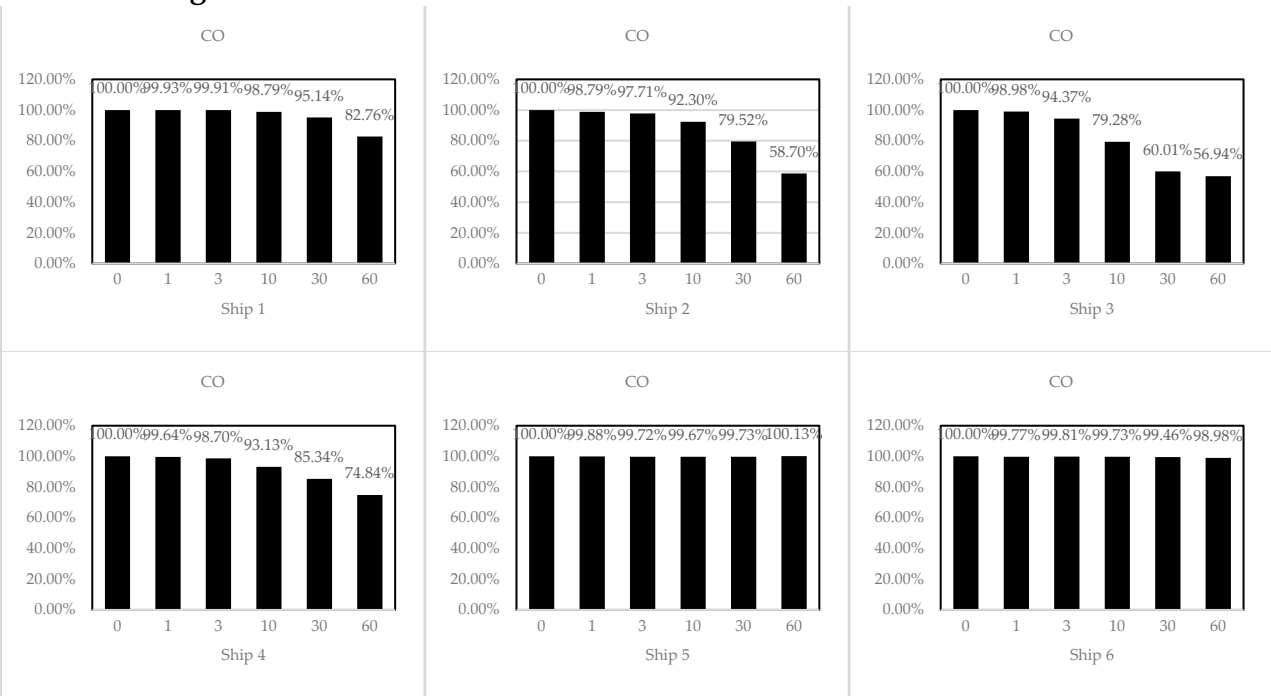


Figure S1. Emissions of CO for the six ships in one day without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

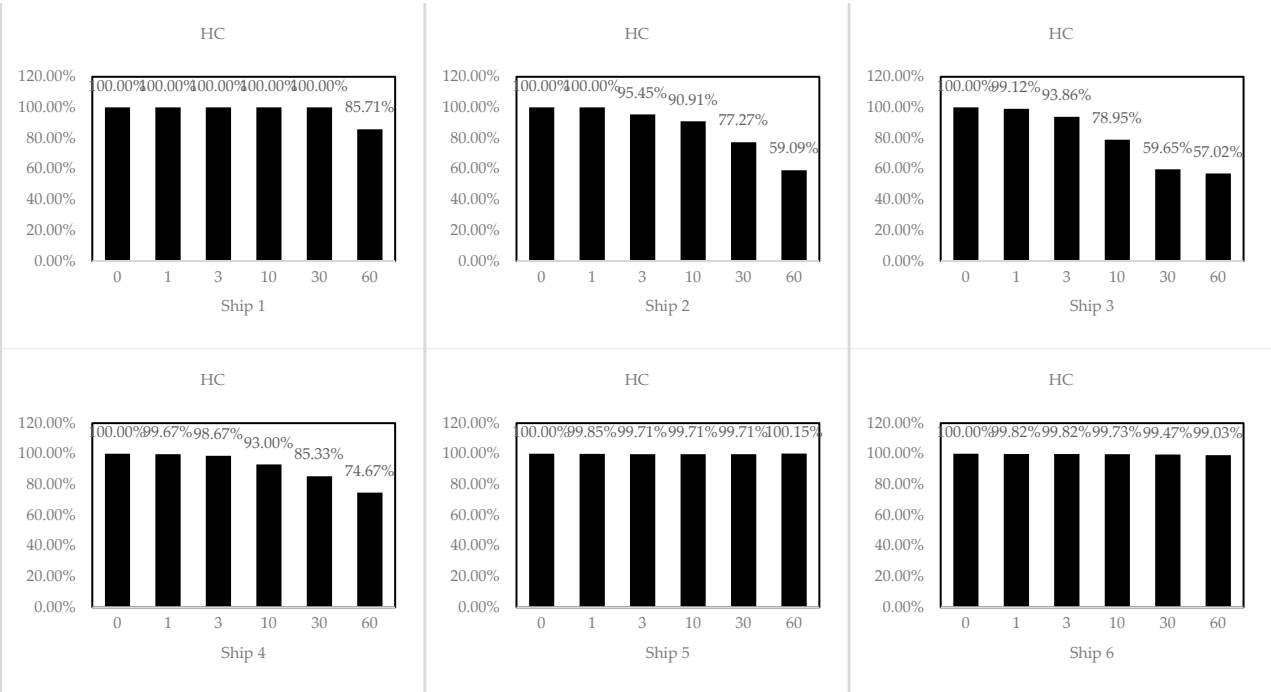


Figure S2. Emissions of HC for the six ships in one day without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

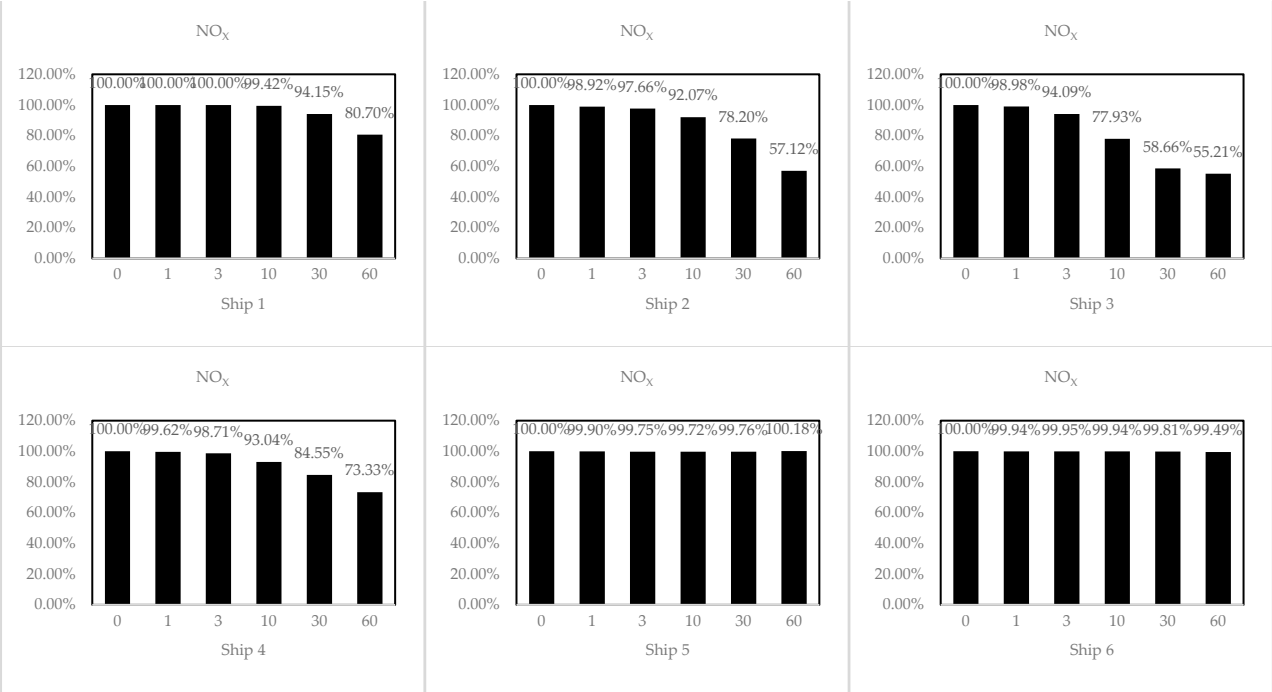


Figure S3. Emissions of NOx for the six ships in one day without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

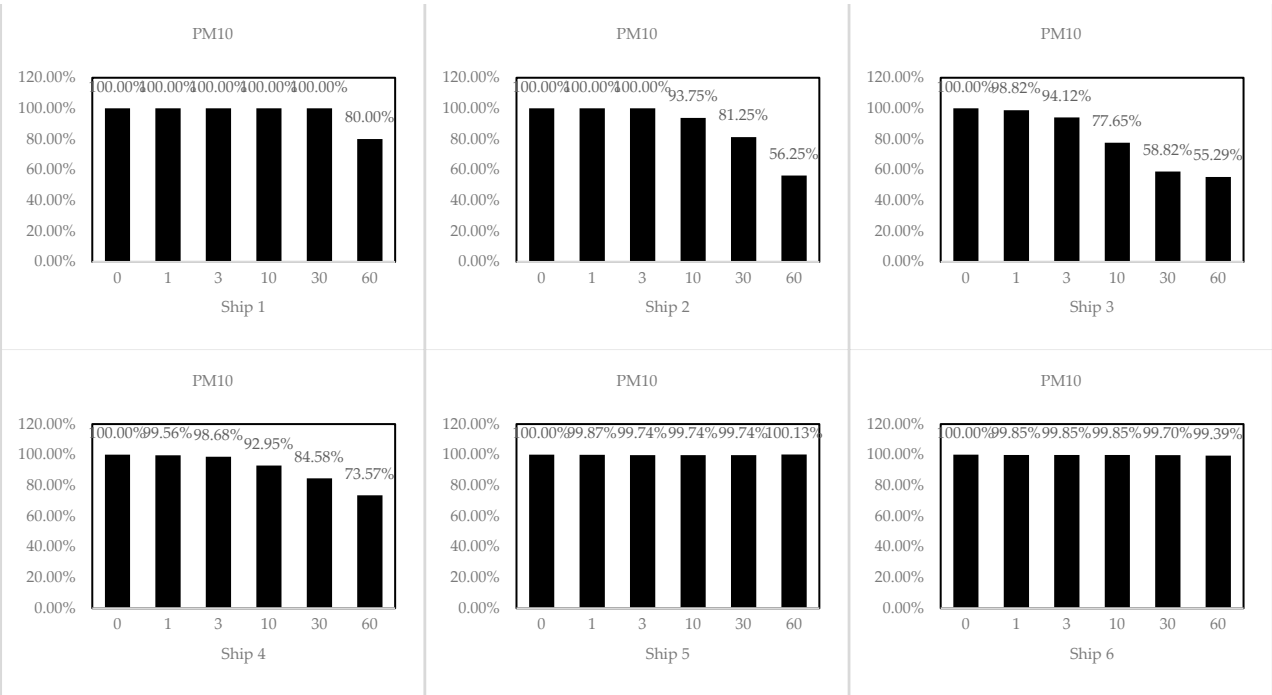


Figure S4. Emissions of PM10 for the six ships in one day without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

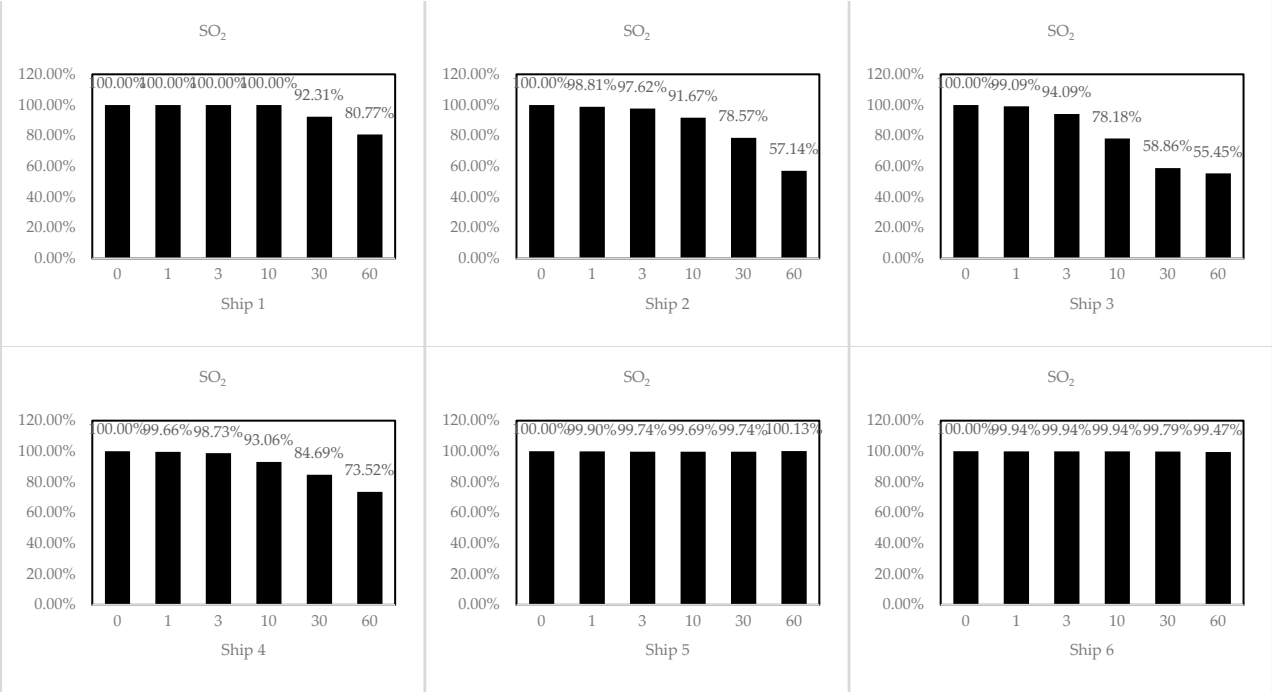


Figure S5. Emissions of SO_2 for the six ships in one day without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

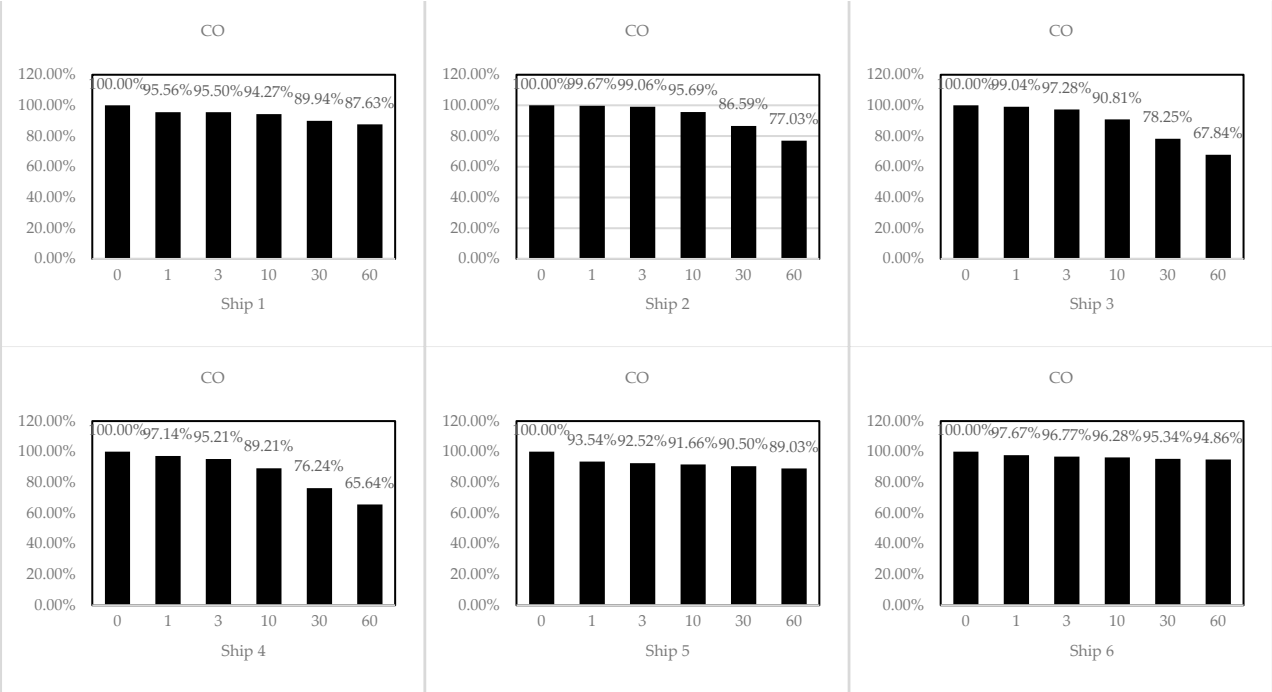
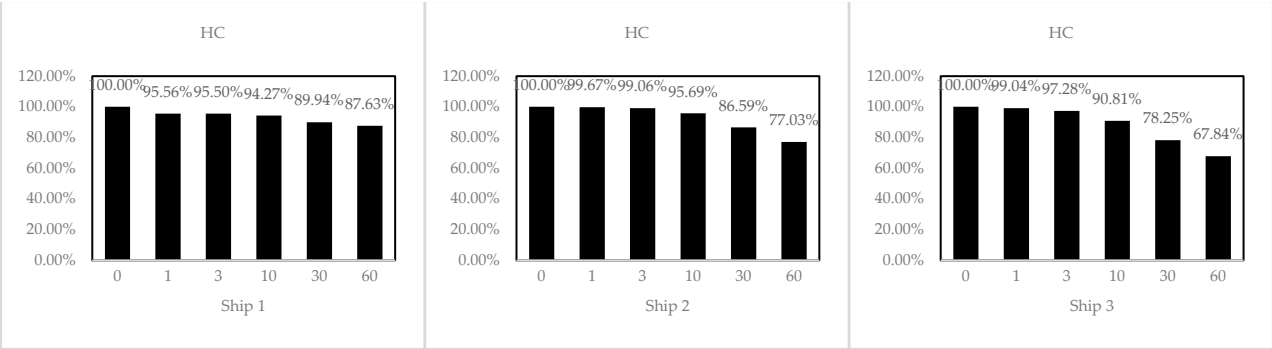


Figure S6. Emissions of CO for the six ships in one year without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.



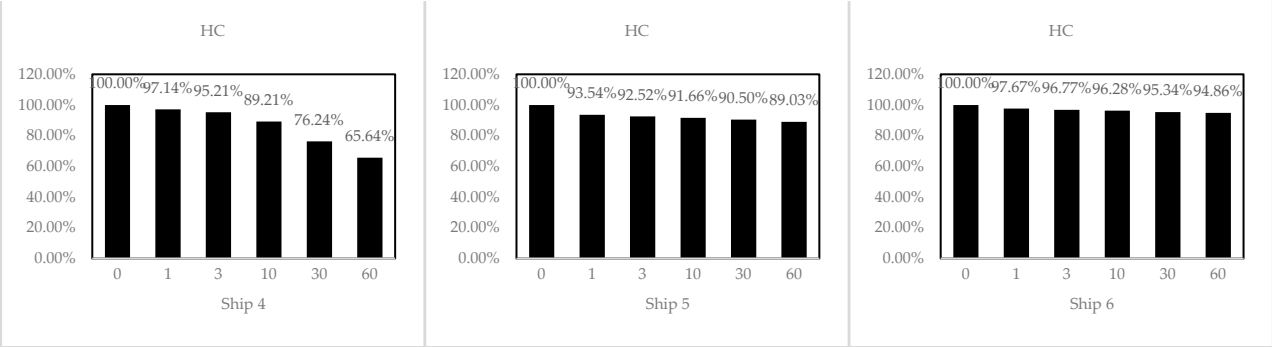


Figure S7. Emissions of HC for the six ships in one year without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

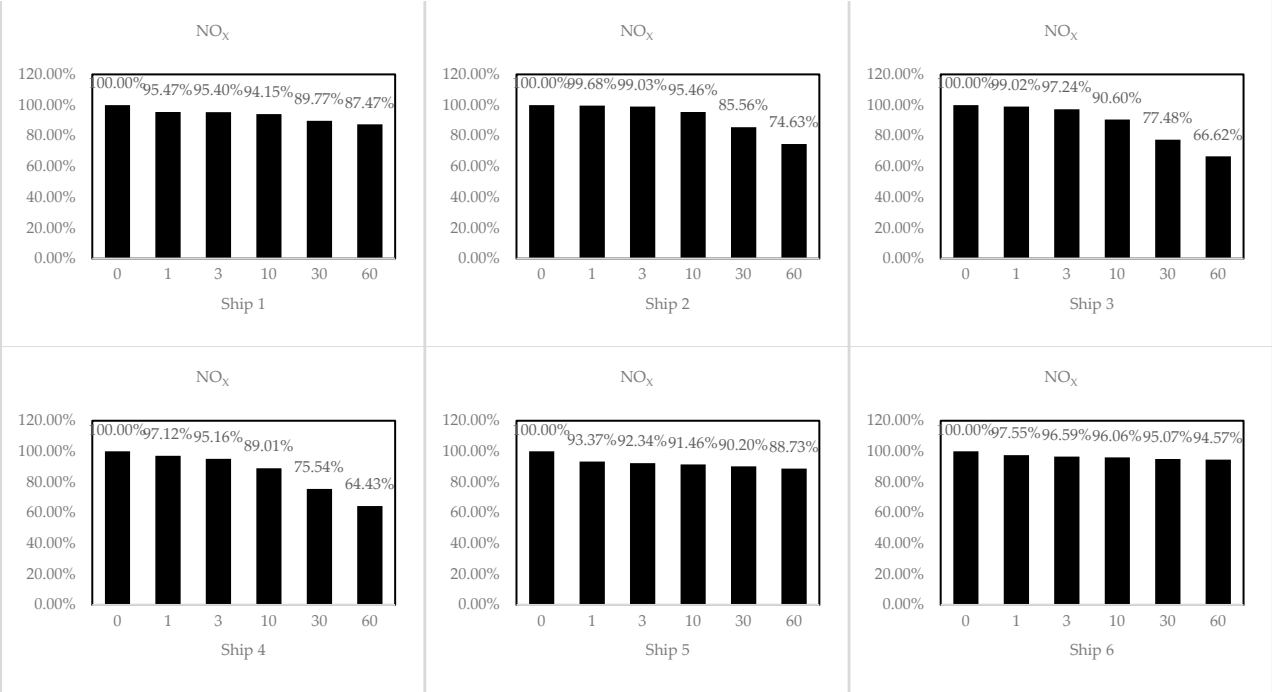
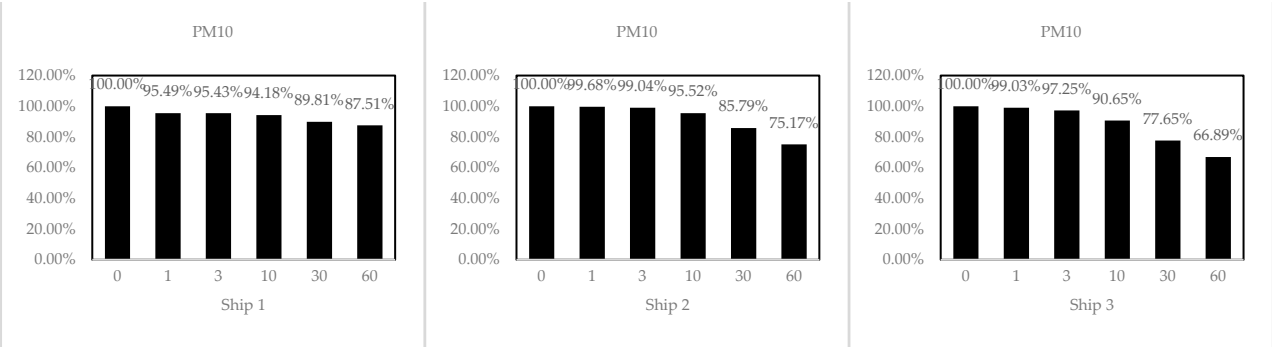


Figure S8. Emissions of NOx for the six ships in one year without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.



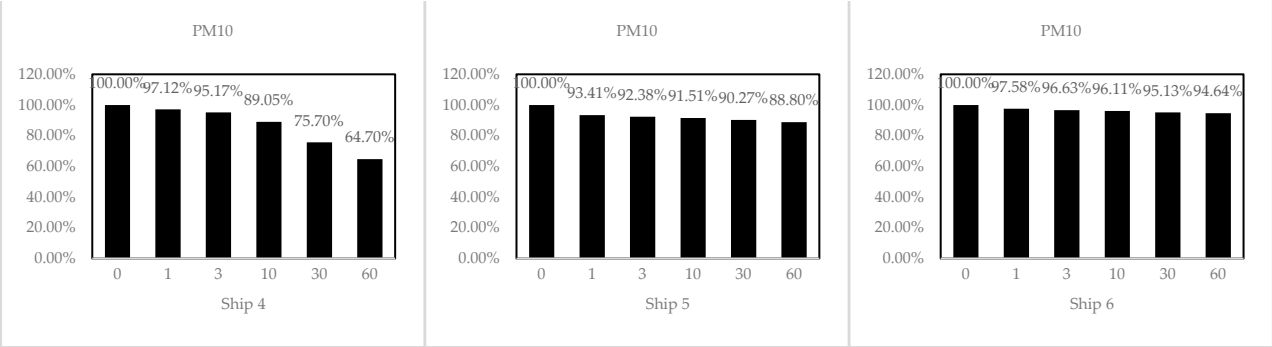


Figure S9. Emissions of PM10 for the six ships in one year without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.

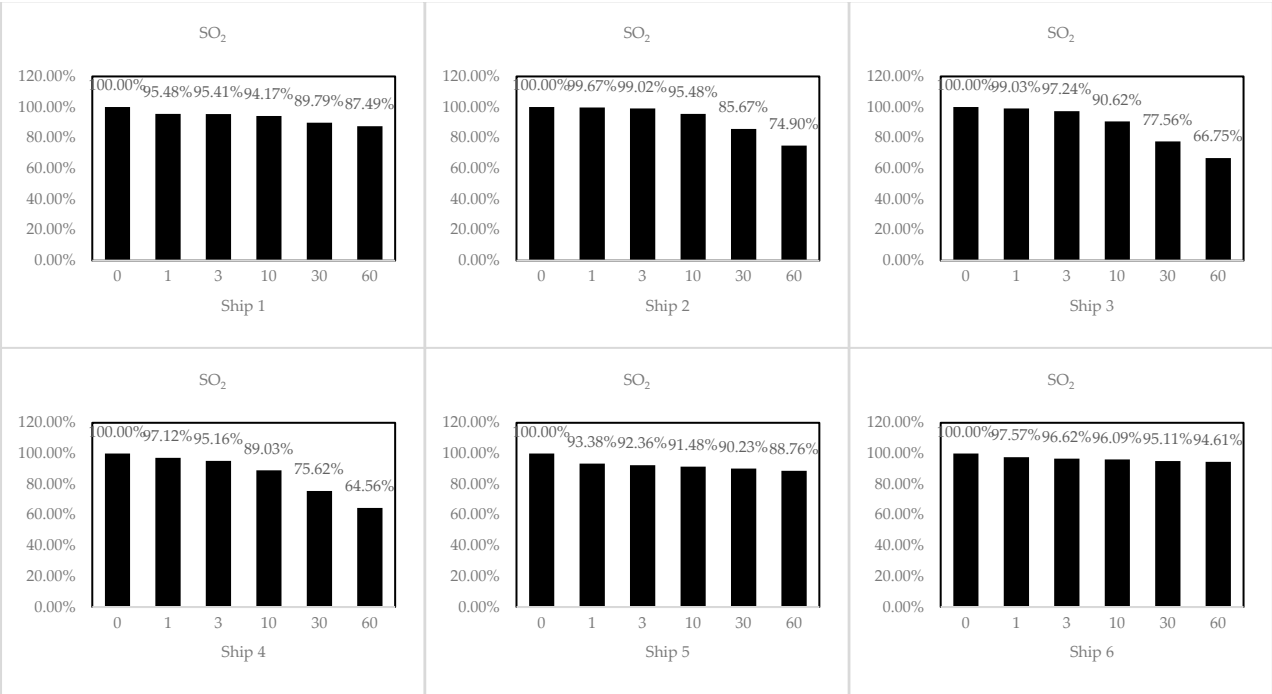


Figure S10. Emissions of SO_2 for the six ships in one year without thinning and with thinning at time interval of 1, 3, 10, 30, 60 mins.