Impact of vessel activities in the surrounding waters of China on mainland air quality

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Abstract. Based on the WRF-CMAQ air quality model, quantitatively simulate the impact of the main air pollutant emissions from the ship transportation activities in the surrounding waters on the urban ambient air quality in coastal areas. The results show that in 2014, the annual average contribution rates of NOx, SO2, PM2.5 and PM10 generated by ship activities in coastal areas of China were 5.95%, 2.20%, 1.46% and 1.41%, respectively. The time difference between ship emissions and air quality impact is significant. The average contribution of ships in April and July is about 10% and 3.5%, and the contribution in January and October is only 2% and 0.93%. The contribution rate of ship activities to the annual average concentration in the coastal waters of China is less than 6%. The impact of coastal ship operations on ambient air quality is generally small.

1. Introduction
The prosperity of maritime trade is a powerful driving force for China's economic prosperity and development. At the same time, the increase in vessel activities has led to the increasingly serious emission of air pollutants from vessels, and the enormous pressure and challenge brought to the air quality in coastal areas is not small. Hey. Several products and by-products are released into the atmosphere during the operation of the vessel's main and auxiliary engines: carbon dioxide, nitrogen oxides, sulfur dioxide, particulate matter, volatile organic compounds., black/elemental carbon and organic carbon[1]. Due to the high average sulfur content in marine heavy fuels, sulfur dioxide emissions are high. Vessel emissions are characterized by a distribution along a typical vesselping route connecting the world's port network[2]. According to different studies, 70 % or more of international vesselping emissions occur within 400 km of the land[3], and the discharge of vessels in the surrounding waters of China mainly occurs within 200 km of the land[4].

In recent years, with the continuous attention of international organizations and local governments on the impact of vessel emissions, domestic and foreign scholars have carried out a lot of research. Ye Siqi used the CMAQ model to simulate the contribution of vessel discharge in the 2012 heavy pollution period in the Pearl River Delta region[5]; Liu et al. Use the CMAQ model The impact of vessel emissions in 2010 on air quality in Shanghai was simulated[6]. However, the impact of sailing vessels in the surrounding coastal areas of China has rarely been reported. In view of this, assess the impact of recent events on the waters surrounding the vessel's air quality has a strong practical significance. Therefore, this study near the waters surrounding the vessel China-based research group to develop emissions inventories[4], quantitative analysis assesses the annual contribution to the emissions of nearly waters
around the vessel in mainland China on air quality using the WRF-CMAQ models and scenarios, and to explore for Characteristics of air quality impacts in major coastal port areas.

2. research method

2.1 Model selection
This article adopts WRF mesoscale meteorological model, CMAQ empty The gas mass model simulates the impact of air pollutant emissions from vessels in the surrounding seas on the air quality in the land area. The CMAQ (Community Multiscale Air Quality) mode system is the core of the third generation air quality model and can therefore be called Models-3/CMAQ mode. The biggest feature of CMAQ is the concept of One-Atmosphere, which breaks through the traditional model for the simulation of single species and single-phase species, complex air pollution such as tropospheric ozone, PM, poisons, acid deposition and visibility. Such as the comprehensive treatment of problems, for multi-scale, multi-pollutant air quality forecasting, evaluation and decision-making research and other purposes.

2.2 model settings

2.2.1 WRF model. This study uses WRFv3.5.1, meteorological physics solutions include Lin et al. microphysical scheme, Goddard shortwave radiation scheme, RRTM longwave radiation scheme, YUS boundary layer meteorological scheme, Noah land use scheme, Grell-Devenyi cumulus scheme. The meteorological initial field data was released by the National Environmental Prediction Center (NCEP) meteorological reanalysis data with a grid resolution of 1°×1° and a time resolution of 6 hours. The terrain and land use data are based on the global 30-second resolution topographic data of the USGS (US Geological Survey), in which the natural source emissions are calculated online based on the land use data.

2.2.2 CMAQ model. The simulated area is centered at (102.5°E, 36.5°N), as shown in Figure 1. The grid resolution is 36km and the number of grids is 120×144, including the entire China range; covering Chinese coastal cities. The analog area is set in the vertical direction 9 pressure layers, The layer spacing increases from bottom to top. In this study CMAQv5.0.2 version, mention five days starting mode to reduce uncertainties initial field; boundary conditions employed background value clean air, clean air using an initial concentration field background field; vapor phase chemical mechanism employed CB05 released in 2005, The aerosol reaction mechanism was Aero6. This study selected January 2014 (summer), 4 months (summer), July (Fall) and 10 months (winter) period 4 as a typical all simulation period.

Figure 1 Schematic diagram of the simulation area
2.2.3 Pollution source emission list. The land-source source emissions inventory uses a multi-scale emissions inventory developed by Tsinghua University that can be used directly by the model. The list divides anthropogenic sources into five categories: electricity, industry, civil, transportation, and agricultural sources. The list covers 10 main atmospheric pollutants and greenhouse gases (SO₂, NOₓ, CO, NMVOC, NH₃, CO₂, PM₂.5, CO₂, PM₁₀, BC/EC) and more than 700 kinds of anthropogenic sources, which integrates the latest dynamic emission inventory method and localized emission factor database enable seamless integration with air quality models, providing a multi-layer nested high spatial and temporal resolution emissions inventory that can be used directly by the model.

The vessel source emission list is based on the real-time dynamic vessel discharge list of the Ministry of Transport's Water Transport Science Research Institute [4]. This list can provide a vessel discharge list with a time resolution of 5 minutes and a spatial resolution of 1km. Multi-layer nested high-temporal resolution emission inventory for direct use.

2.3 simulation verification

In order to ensure the accuracy and reliability of the air quality simulation results, the built simulation platform needs to be verified before the simulation. The meteorological observation data and the air pollutant concentration monitoring data provided by the air quality monitoring network can usually be used to verify the reliability of the simulation results.

For meteorological field simulation, many meteorological parameters will have different effects on the simulation results. The most influential parameters are wind speed, wind direction, relative humidity and temperature. It is usually possible to verify the reliability of meteorological simulation by comparing the meteorological observation data obtained by the surface meteorological observation station with the simulated value of the meteorological field grid in the WRF. The temperature and wind speed monitoring data in the MICAPS system data of the National Meteorological Data Center are compared with the 2014 results of the WRF simulation. The results show that the WRF mode has a good simulation effect on temperature and wind speed changes, indicating that the WRF mode is used for meteorology. Simulation is possible.

In addition to meteorological data, the concentration of pollutants provided by the air quality monitoring grid of the study area is compared with the air pollutant concentration corresponding to the air quality simulation results to verify the reliability of the air quality model simulation results. The quantitative analysis is mainly carried out by calculating the standard average error and the standardized mean deviation between the pollutant observation value and the model simulation concentration. If the values are less than 50%, the simulation result of the mode is better. Table 1 shows the standardized average deviation and standardized average error of the simulated concentration value of pollutants and the actual monitored values.

| Contaminant | month | SO₂ (%) | NO₂ (%) | PM₁₀ (%) |
|------------|-------|---------|---------|----------|
| NMB (%)    | January | -34     | 20      | -48      |
| NME (%)    |        | 42      | 35      | 54       |
| NMB (%)    | April  | twenty four | 10      | -47      |
| NME (%)    |        | 43      | twenty three | 49      |
| NMB (%)    | July   | 37      | twenty two | -46     |
| NME (%)    |        | 49      | 34      | 51       |
| NMB (%)    | October| -35     | -13     | -44      |
| NME (%)    |        | 48      | 32      | 51       |

2.4 scenario design

Using the above air quality simulation platform, this study set up two scenarios for simulation analysis. By comparing the simulation results of the two scenarios, the extent and extent of the impact of Chinese vessel emissions on air quality are analyzed. The two scenarios are set as follows: (1) Non-vessel scenario: the impact of vessel emissions is not included in the simulation source list input, and the
vessel pollutant emissions are set to zero; (2) vessel discharge scenario: based on the baseline scenario during simulation Join the established vessel emissions list. In order to effectively impact assessment of ambient air quality emissions from vessels, from the point of view of the analysis: emissions from vessels scope of analysis, the scope and extent of the impact of emissions from vessels of China; the average monthly contribution of vessel emissions analysis, respectively, four months The monthly mean value of each pollutant concentration in the vessel discharge scenario is different from the monthly mean value of the pollutant concentration in the vessel-free scenario. The difference obtained is divided by the monthly mean value of each pollutant concentration in the vessel discharge scenario, and the monthly contribution rate of the vessel discharge is obtained.

3. results and analysis

3.1 month average contribution of vessel emissions characteristics
The figure 2 to 5 shows the simulation results of vessel emission in the January, April, July, October with NO\textsubscript{x}, SO\textsubscript{2}, PM\textsubscript{10} and PM\textsubscript{2.5}. It can be seen from the figure that ship emissions have different effects on the range and extent of NO\textsubscript{x}, SO\textsubscript{2}, PM\textsubscript{2.5} and PM\textsubscript{10} concentrations in China's coastal areas. Ship emissions are not only simulated high values in marine areas where ship activities are frequent. Due to the effects of weather conditions, the migration and diffusion process of pollutants will also have different degrees of impact on coastal inland areas. Overall, ship emissions have a greater impact on areas closer to the offshore line.

![Figure 2. Effect of vessel NO\textsubscript{x} emission spatial distribution simulation results](image)

![Figure 3. Effect of vessel SO\textsubscript{2} emission spatial distribution simulation results](image)

![Figure 4. Effect of vessel PM\textsubscript{2.5} emission spatial distribution simulation results](image)
Figure 5. Effect of vessel PM$_{10}$ emission spatial distribution simulation results

From a time perspective, the overall trend of the impact of ship emissions on pollutant concentrations in different months is the same. The effects in April and July are higher than in January and October, as shown in Table 2. The contribution ratio of ship emissions to NO$_x$, SO$_2$, PM$_{2.5}$, and PM$_{10}$ concentrations in China in January was 2.21%, 0.88%, 0.45%, and 0.45%, respectively; The contribution ratio of ship emissions to NO$_x$, SO$_2$, PM$_{2.5}$, and PM$_{10}$ concentrations in China in April was 10.67%, 3.93%, 2.34%, and 2.15%, respectively; The contribution ratio of ship emissions to NO$_x$, SO$_2$, PM$_{2.5}$, and PM$_{10}$ concentrations in China in July was 9.23%, 3.02%, 2.39%, and 2.27%, respectively; The contribution ratio of ship emissions to NO$_x$, SO$_2$, PM$_{2.5}$, and PM$_{10}$ concentrations in China in October was 1.69%, 0.98%, 0.64%, and 0.78%, respectively.

Table 2  Monthly average contribution of marine air pollutants

| Contaminant | NOx | SO$_2$ | PM$_{2.5}$ | PM$_{10}$ |
|-------------|-----|--------|------------|-----------|
| Monthly average |     |        |            |           |
| January       | 2.21% | 0.88%   | 0.45%      | 0.45%   |
| April         | 10.67% | 3.93%   | 2.34%      | 2.15%   |
| July          | 9.23%  | 3.02%   | 2.39%      | 2.27%   |
| October       | 1.69%  | 0.98%   | 0.64%      | 0.78%   |
| average       | 5.95%  | 2.20%   | 1.46%      | 1.41%   |

3.2 Analysis of the influence of vessels in major port cities

Seven major port cities were selected to analyze their hourly ship emissions contribution for the four months of January, April, July, and October, as shown in Table 3. It can be seen from Table 3 that for different major port cities, the contribution of NO$_x$ and SO$_2$ is greater than PM$_{10}$ and PM$_{2.5}$. Mainly because NO$_x$ and SO$_2$ are primary pollutants directly discharged by ships, and NO$_x$ and SO$_2$ emissions are higher than PM$_{10}$ and PM$_{2.5}$. The contribution of NO$_x$ and SO$_2$ is large, mainly because NO$_x$ and SO$_2$ are primary pollutants directly discharged by ships. From the perspective of monthly contribution, the contribution in April and July is higher than in other months.

Table 3  The typical port area represents the monthly and monthly average vessel impact

| Contaminant | month | Dalian | Qinhuangdao | Tianjin | Qingdao | Ningbo-Zhoushan | Guangzhou | Shenzhen |
|-------------|-------|--------|-------------|---------|---------|-----------------|-----------|---------|
| NO$_x$      |       |        |             |         |         |                 |           |         |
| January     | 13.5% | 3.1%   | 0.5%        | 5.7%    | 1.8%    | 3.2%            | 5.6%     |         |
| April       | 2.62% | 1.87%  | 4.9%        | 12.4%   | 2.78%   | 6.3%            | 22.4%    |         |
| July        | 1.96% | 1.69%  | 7.5%        | 10.6%   | 3.18%   | 2.5%            | 23.8%    |         |
| October     | 8.4%  | 7.5%   | 0.7%        | 7.8%    | 1.48%   | 0.1%            | 3.5%     |         |
| SO$_2$      |       |        |             |         |         |                 |           |         |
| January     | 7.1%  | 2.0%   | 0.4%        | 3.4%    | 35.9%   | 2.9%            | 8.1%     |         |
| April       | 37.4% | 18.5%  | 4.1%        | 11.8%   | 40.6%   | 6.7%            | 25.5%    |         |
| July        | 35.8% | 16.5%  | 7.1%        | 13.0%   | 49.7%   | 2.1%            | 27.4%    |         |
| October     | 7.9%  | 4.3%   | 0.7%        | 4.8%    | 57.8%   | 1.6%            | 4.5%     |         |
| PM$_{2.5}$  |       |        |             |         |         |                 |           |         |
| January     | 0.6%  | 0.3%   | 0.1%        | 0.8%    | 12.4%   | 2.8%            | 3.6%     |         |
| April       | 2.1%  | 1.1%   | 0.7%        | 3.7%    | 22.4%   | 8.7%            | 19.1%    |         |
| July        | 4.6%  | 4.0%   | 1.8%        | 5.5%    | 29.5%   | 5.3%            | 21.0%    |         |
| October     | 1.0%  | 0.5%   | 0.3%        | 1.6%    | 18.6%   | 3.4%            | 3.5%     |         |
| PM$_{10}$   |       |        |             |         |         |                 |           |         |
| January     | 0.6%  | 0.3%   | 0.0%        | 0.6%    | 6.7%    | 2.8%            | 3.0%     |         |
| April       | 1.1%  | 0.4%   | 0.4%        | 3.0%    | 20.2%   | 7.4%            | 14.3%    |         |
| July        | 3.9%  | 4.2%   | 1.6%        | 4.2%    | 34.2%   | 4.5%            | 14.9%    |         |
| October     | 0.9%  | 0.4%   | 0.2%        | 1.3%    | 15.0%   | 3.2%            | 2.8%     |         |
From the geographical location of the port, Dalian and Ningbo-Zhoushan are peninsula-type landforms, and their location protrudes into the sea. The land is surrounded by the navigation channels of surrounding ships. So the analysis from the urban area is more affected. Conversely, cities that are recessed into land are less affected by ship activities.

4. Conclusion
This study established a nearly air quality of the surrounding waters simulation platform, quantitative method for simulating scenarios vessel activities coastal areas where the air discharged NO$_x$, SO$_2$, PM$_{10}$ and PM$_{2.5}$ tribute. The characteristics and key influencing factors of time and space change were discussed and analyzed. The main conclusions are as follows:

1) vessel emissions coastal areas NO$_x$, SO$_2$, PM$_{10}$ and PM$_{2.5}$ on average concentration contributions were 5.95%, 2.20%, 1.46% and 1.41%.

2) The time difference between vessel discharge and air quality is significant. To NO$_x$, SO$_2$, the average contribution of the vessel in April and July of about 10% and 3.5%, the contribution in January and October only 2% and 0.93%.

3) At the city scale, for the entire coastal area and major port areas, the contribution of NO$_x$ and SO$_2$ is greater than that of PM$_{10}$ and PM$_{2.5}$.

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