SHIP AIR EMISSIONS: ESTIMATION AND REGULATION

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Diesel engines power 95% of the world's oceangoing ships. The global and regional impact of air pollution from ship engines not been addressed until quite recently. The fact that international ship emissions contribute approximately 2% of carbon emissions from human activity has veiled their greater contribution to global pollution of nitrogen and sulfur. Ship engine emissions contribute approximately 14% of nitrogen emissions from all fossil fuel, and approximately 16% of sulfur emissions from all petroleum sources (5% of sulfur from all fossil fuels including coal). Current policy efforts by International Maritime Organization (IMO) provide the first attempts to limit air pollution from ships involved in international trade. This summary presents current work in this area that updates the science available to global change researchers, international policy makers, and industry stakeholders.

INTRODUCTION

Study of air pollution from shipping has typically been limited to its impact on local air pollution in busy ports suffering significant air quality challenges, such as Los Angeles and Yokohama. Additionally, concern has focused on visible emissions until recently. With our growing understanding of the role of aerosols in climate change, it is important to study the scale and geographic pattern of ship emissions globally. Prior to this study, fuel inventories used for generating maps of global areosol concentrations assigned ship emissions to land masses where the ships are fueled – thus failing to take appropriate account of ship emissions. As a result, the information describing the impact of shipping both globally and locally has not been available to policy makers or global change researchers.

Currently, many U.S. states regulate opacity (smoke) emissions from international and domestic ships while transiting coastal or port waters. However, nitrogen and sulfur pollution from ship propulsion remains uncontrolled globally. The IMO plans to vote on proposed limits during their fall 1997 diplomatic session and the U.S. Environmental Protection Agency will develop regulations following international action. Similar to other precedent-setting environmental policy measures, the debate over ship air pollution has suffered from the inadequacy of available science regarding global ship emissions. Without an analysis of global ship emissions and their relative importance compared to other sources, policy makers are limited to a handful of port and regional studies that at their best evaluate the efficacy of regulation locally, and at worst skew the discussion by choosing small scales (in horizontal and vertical extent) to argue insignificant impacts from ship propulsion emissions.

Ship emissions are significantly larger than previously considered – on the order of domestic nitrogen and sulfur emissions inventories from the largest emitting nations. Moreover, these emissions are not constrained to remote ocean regions or distributed homogeneously; rather ship emissions are concentrated along well-defined trade routes between highly populated regions where regional air quality is a prime concern. In assessing the global inventory of ship emissions, we used current emission test data for ships. As shown in Table 1, approximately 55% of the registered vessels use slow speed diesel propulsion. Medium speed diesel engines power another 40% of the world's registered ships, either in diesel-gear or diesel-electric propulsion. All other types of ship propulsion account for 5%, the most common non-diesel propulsion being steam turbine technology.

Table 1. World Ship Engine Profile

Engine Types .	Military Fleet	Commercial Fleet	Total Fleet
Slow Speed Diesel	1,289 (7%)	56,628 (66%)	58,287 (55%)
Medium Speed Diesel	14,940 (76%)	27,758 (32%)	41,894 (40%)
Steam and Others	3,417 (17%)	1,820 (2%)	5,673 (5%)
Total Vessels	19,646	86,206	105,854

We estimated the global annual nitrogen and sulfur emissions from ships to be 3.2 million metric tons and 4.2 million metric tons, respectively. Not only are these values equivalent to nitrogen and sulfur emissions from the largest energy-consuming nations; they represent more than 14% of nitrogen emissions from global fuel combustion sources and more than 16% of sulfur emissions from world petroleum use.

COMPARISON AND POTENTIAL IMPACT

Figure 1 compares ship nitrogen emissions with domestic nitrogen emissions reported for several OECD nations and with global inventories. Figure 2 compares ship sulfur emissions with domestic and global sulfur inventories. Worldwide ship nitrogen emissions are equal to 42% of nitrogen emissions from North America, nearly half of the total emissions from the U.S., 74% from OECD Europe, and 1.9 times that of East and West Germany (1) They are equal to 87% of nitrogen emissions from U.S. stationary sources and equal to of those from U.S. mobile sources. Ship sulfur emissions equal 35% of sulfur emissions from North America, 43% of total sulfur emissions from the U.S., 53% from OECD Europe, and 178% from Germany. Most of the continental sulfur emissions are from stationary sources.

Ship emissions account for 14% of nitrogen emissions from fossil fuels (2) and 16% of all sulfur from petroleum uses. Ship sulfur accounts for 5% of sulfur emitted by all fuel combustion sources. This is equivalent to 10% of sulfur from hard coal combustion and 45% from lignite combustion. Carbon dioxide emissions from ships are only 2% of the 6000 Tg carbon emitted from fossil fuel use (3). Ship engines are thus among the world's highest polluting combustion sources per ton fuel consumed.

Moreover, these emissions are not constrained to remote ocean regions or distributed homogeneously; rather ship emissions are concentrated along well-defined trade routes between highly populated regions where regional air quality is a prime concern. This was confirmed by developing a ship emission density profile using the *Comprehensive Ocean-Atmosphere Data Set (COADS), Standard 1a*, from the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmosphere Administration (NOAA) (4). "The Comprehensive Ocean-Atmosphere Data Set (COADS) is the most extensive collection of surface marine data available for the world ocean over the past century and a half" (5). *COADS Standard 1a* is a subset of one of the longest continuous climate records in existence, begun in 1854 by international agreement of the world maritime nations. The *Standard 1a* data set summarizes on a 2° latitude by 2° longitude (2° x 2°) resolution ship location and weather observations taken by merchant and naval mariners covering the period of 1980-93. By dividing the global sulfur emissions by the traffic density derived from COADS, we characterized the emissions density geographically.

While we have not yet modeled transport distances explicitly for ship emissions, initial review of the literature suggests "that the median transport velocity is about 400 km per day. Emitted SO_2 and NO and their atmospheric oxidation products are thought to have mean residence times of ~1 to ~3 days, indicating mean transport distances of ~400 to

"1200 km" (6). More recent studies demonstrate that while the characteristic transport distance over the North Atlantic region depends on direction, "the minimum value of the average is 900 km and the minimum values for the 10th and 90th percentiles are 400 and 1,700 km" (7). Based on this literature, 400 km appears to be a lower-bound transport distance in regions where the wind direction may transport ship emissions toward land..

POLICY ISSUES

Global emission limits proposed by the IMO may soon be enacted. NOx regulations will apply only to new ships or major ship conversions on or after 1 January 2000. For a yearly fleet replacement rate of 1.5% of 106,000 ships (8) after the year 2000, measurable reduction in global nitrogen emissions from ships will not occur for many years. For NOx controls that reduce emissions by 30% to 50%, IMO regulations would reduce emissions by less than 1% per year. Current IMO language limits fuel-sulfur levels to 5% (9). This provides little reduction if any, and practically codifies the status quo, since International Organization for Standardization fuel standards set a 5% sulfur limit in 1987. However, both of these global limits are valuable, because adoption of the IMO regulation means multinational consensus on the principles of emission control. Under IMO criteria, regional efforts must include trade-off considerations to determine the utility of more stringent regulation.

Two policy domains must be considered: (i) nations providing international marine fuel to ships; and (ii) nations registering commercial vessels. International fuel provided by the top 20 nations accounts for 82% of global ship emissions, using the Energy Information Agency international marine-fuel data (10). The top 20 of 206 nations with registered vessels account for 56% of the world ships. Ships registered to these top 20 nations emit between 55% and 65% of global ship nitrogen and sulfur emissions. However, ten of these nations are considered foreign registers (sometimes referred to as "flags of convenience"), since vessel ownership is in another nation. Foreign flag registry has increased recently (8). In other words, emissions from ships attributed to nations of registry would be significantly different than emissions from ships attributed to nations of ownership. Strict enforcement policies aimed at registering nations may inadvertently shift which foreign nation registries are selected by vessel owners, instead of achieving emission reduction goals.

Another problem is that open-market interests and treaty commitments may limit strict emission control strategies for ships. Moreover, in most cases, cargo transport by ship produces lower emissions than other modes of transport. Without attention to these policy issues, the potential exists to affect the flow of trade in unplanned ways (e.g., by creating incentives for developing port areas to adopt less stringent requirements than current shipping destinations). This could increase environmental emissions from cargo transport, especially if modes with higher emissions per ton cargo (such as rail or truck) become substitutes for ship transport.

However, the policy horizon is even more complex than these characterizations suggest. Individual nations and regional interests (such as the U.S. EPA and the Baltic states) can be expected to adopt more stringent emission controls than the IMO language provides. Motivation for this will be the contribution from ship emissions to regional air quality problems, including other pollutants such as particulate matter. Reducing ship propulsion emissions with minimum trade-off in engine operation, cost, etc., can best be implemented in new engine design. With the low replacement rate for ships and ship engines, regulations limiting pollution from existing engines may be developed. Developing effective control strategies will require that three criteria are balanced: 1) Technologies controlling emissions need to preserve fuel economies; 2) Policy strategies must ensure that controls can be implemented via international companies without negatively affecting trade; and 3) Compliance and/or enforcement of emission controls must be verifiable by those communities most affected by pollution from ship traffic

CONCLUSIONS

International ship nitrogen and sulfur emissions are larger than previously considered, with estimates on the order of the largest nations' domestic emissions. Characterizing these emissions geographically, they are concentrated in the northern hemisphere, particularly along heavily traded routes. Current IMO policy provides an extremely important international framework for control of ship emissions, although the current regulatory provisions may not reduce global emissions until well into the 21st century, except in areas of stricter control. Increased policy focus will result from improved understanding of the science of marine diesel emissions, although it may be limited by economic and environmental trade-offs. Manufacturers and operators of large marine engines need to maintain the dialogue with pollution scientists and policy makers to ensure that emissions control strategies for ships balance the complex criteria motivating (and constraining) action.

This DEER paper (and presentation) summarizes the following article: J. J. Corbett, P. S. Fischbeck, *"Emissions From Ships"*,. Science, Volume 278, Number 5339, 31 October 1997, pages 823-824.

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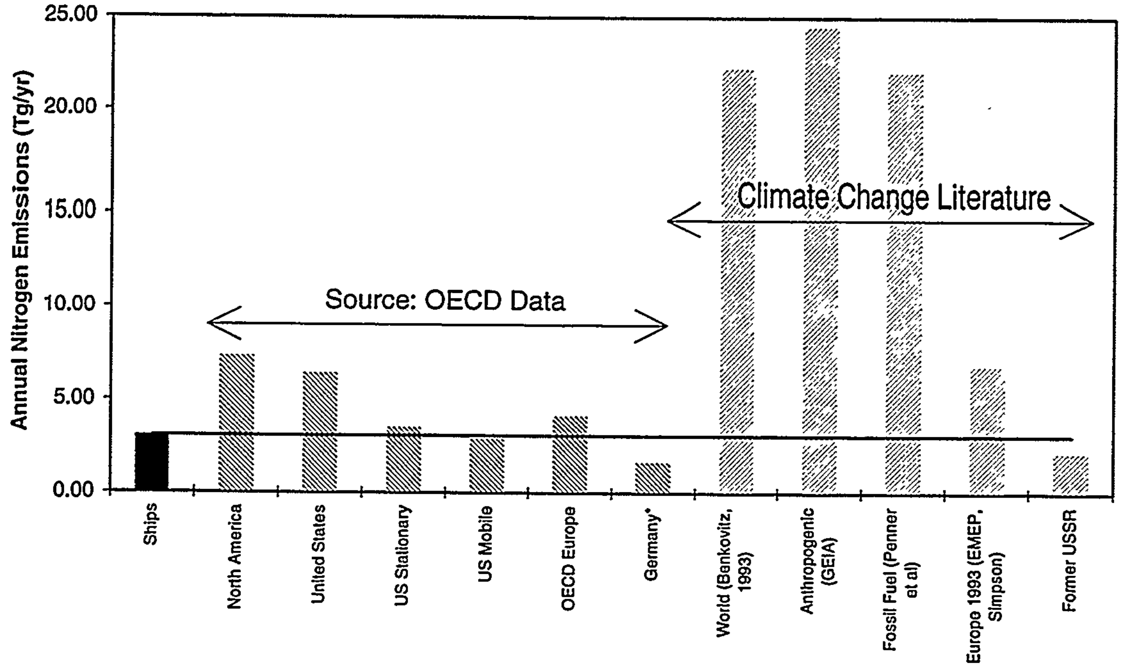

Figure 1. Comparison of Ship Nitrogen Emissions with Other Global Source Inventories

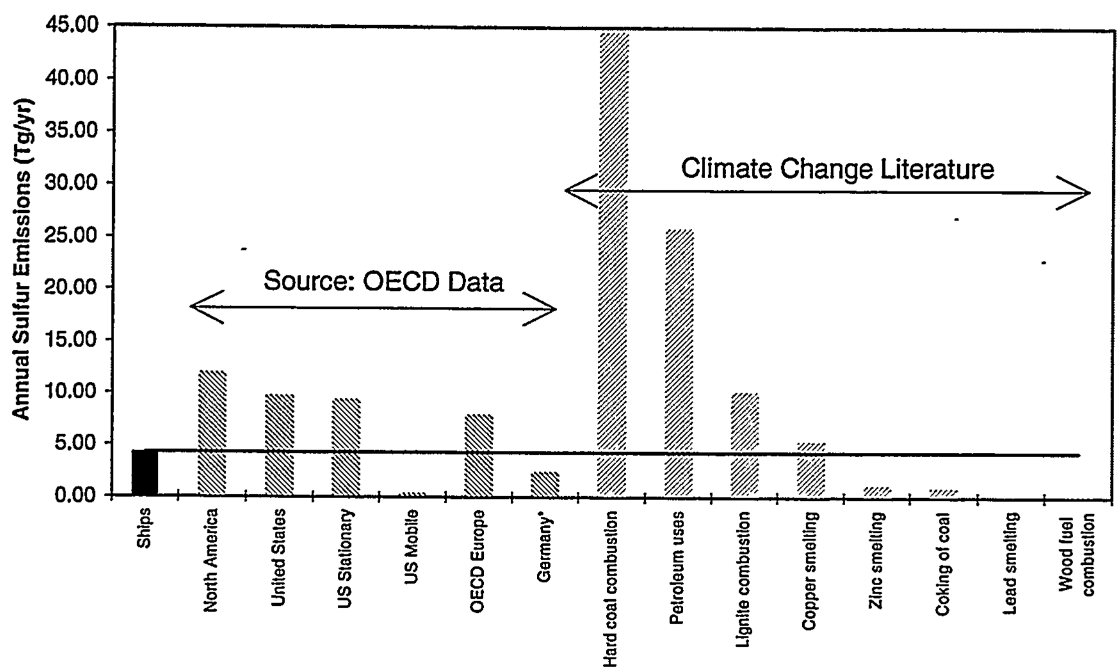

Figure 2. Comparison of Ship Sulfur Emissions with Other Global Source Inventories