Updated Emissions from Ocean Shipping

James J. Corbett
Assistant Professor, Marine Policy, College of Marine Studies, University of Delaware, 118 Robinson Hall, Newark, DE 19710, jcorbett@udel.edu

Summary of Project

Emissions from ships have been shown to have local, regional, and global impacts [Olivier, 1996 #293; Corbett, 1997 #252; Corbett, 1998 #324; Skjølsvik, 2000 #476] [European Commission, 2002 #718] [Lloyds Register Engineering Services, 2001 #719]. Pollution and atmospheric scientists have relied on various emissions inventories to quantify the potential environmental impact. Ship emissions inventories for CO_2 and other pollutants have been based on international sales of marine fuels. These previous inventories confirm long held beliefs that marine diesel engines are among the most fuel-efficient combustion sources for moving global resources and products. Nonetheless, these previous global inventories identified international shipping as a significant source of NOx and SOx pollution.

The GEIA shipping inventory effort tracks and reports on the current status of inventory methodologies, including quality of data for inventory calculations and for spatial assignment. To date, there are essentially four related efforts to quantify ship emissions and their potential environmental impacts. These include two global efforts: RIVM's EDGAR database, and the University of Delaware's Ship Emissions Assessment calculations (SEACalc). There are also two ongoing regional inventory programs: RAINS-ASIA (Integrated Assessment of Energy Use Impacts on the Environment in Asia) shipping inventory, and Lloyd's Marine Exhaust Emission Research Programme.

Methodologically, each of these research efforts has similar objectives. They each estimate vessel energy consumption and resulting emissions for the population of ships operating within the study boundaries (regional or global). These estimates are then assigned spatially using a geographical representation of vessel activity. However, global inventories typically rely on less detailed activity data and/or attempt to integrate several regional inventories. For example, the SEACalc uses a subset of world fleet traffic reporting weather data regularly as a statistically representative proxy for the entire fleet. Regional inventories can use better vessel traffic estimates, directly gathering exhaustive port-specific trade or vessel statistics. For example, the Lloyd's study uses actual vessel arrival and departure data in a voyage routing model that produces the most detailed analysis of regional vessel traffic.

Current research under the GEIA project objectives includes updating the methodology for estimating ship emissions for the world fleet. This involves applying the latest emissions factors to fuel-based inventories for previous inventories for 1996, and creating new inventories for years consistent with the GEIA datasets. Along with improved emissions factors, our research is developing better estimates of vessel activity and energy consumption. This research may suggest that current global inventories significantly underestimate oceangoing emissions by including only ship activity related to international marine fuel usage, thereby ignoring all vessel activity associated with coastal and domestic shipping.

There are three basic challenges for the ship inventory assessments related to GEIA: 1) estimating the energy consumed; 2) estimating the resulting emissions; and 3) assigning results to time and location. These problems are not specific to vessel inventories. Non-road sources in general have been less well characterized, primarily because of uncertainties in the locations of activity and in the activity levels. For many mobile sources (both on-road and non-road), a fuel-based inventory approach has been effective. In the case of international shipping, these uncertainties were compounded by limited information about the emissions factors assigned to marine engines.

The fuel-based approach applied to previous ship emissions inventories began with an important assumption that reported world consumption of international marine fuels was accurate and complete. This assumption appears to be wrong. According to international agreement, international marine bunkers cover those quantities delivered to sea-going ships of all flags, including warships. Consumption by ships engaged in transport in inland and coastal waters is not included. [http://www.iea.org/stats/defs/origins/marine.htm]. This includes internal and coastal navigation (including small craft and coastal vessels not purchasing their bunker requirements under international marine bunker contracts). Fuel used for ocean, coastal and inland fishing should be included in agriculture. [http://www.iea.org/stats/defs/origins/internal.htm]. Current efforts to estimate fuel consumption for the world fleet suggests that international fuel sales alone cannot account for the energy required to operate all registered ocean-going vessels [in preparation].

Getting the inventory right is only one problem for evaluating impacts; the other problem involves getting the spatial and temporal characteristics. For example, surrogates like population may not identify the location of large construction projects, and construction or logging equipment may be idle much of the time.

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International shipping provides another example of using unique surrogate data to characterize the geographic domain of a sector's emissions. While ships operate along well-known shipping lanes, these "water highways" are not mapped directly and they vary by season and with the weather. In order to develop gridded emissions inventories for NOx and SOx from shipping, a surrogate for vessel traffic density by location was derived from atmospheric and ocean observations reported by ships participating in the Worldwide Weather Watch. Ship observations in each gridded location are averaged and compiled by month in the Comprehensive Atmosphere Ocean Database (COADS), used by scientists and modelers [1]. Using the number of shipboard observations that were averaged in each grid cell for one attribute (e.g., air temperature), the implied traffic density for commercial shipping can be obtained for each month of the year.

The accuracy of the resulting ship traffic profile depends upon two fundamental assumptions: 1) a statistically significant population of ships reports to COADS; and 2) that sample of ships is representative of the international fleet overall. However, some 16% of the world cargo fleet reports to COADS, and comparison with regional inventories using more direct bottom-up traffic profiles has verified the accuracy of this approach [2, 3]. To complete the emissions inventory, activity level for ship engine systems and emissions factors are applied as in other inventories, discussed above. Figure 1 presents a global inventory of NOx emissions from international shipping.

The surrogate approach has desirable features for global inventories. It directly reveals global resolution and is easily updated for different years, updated activity information, or better emissions factors. It suffers from some of the same limitations as other sectoral inventories. Chief among these are the limited resolution, which results in an increasing loss in confidence if modelers try to "zoom in" beyond a large region to only a few cells. The difficulty is finding appropriate surrogates that can be verified and applied to different years. In the case of shipping, the weather data appears to be robust over the past several decades. The data might not be a good record before, say, 1960 because of changes in fleets or their technologies. Related to this is the challenge of reconciling port-level or regional bottom up inventories with the globally derived data. However, the agreement in many cases appears to be very good and differences are equally attributable to uncertainties in the port- or regional-scale and global-scale inventories.

Ongoing research is also attempting to better characterize the inventories using the 1x1 degree grid standard, and a monthly resolution. Ultimately, the goal is to produce a consistent set of monthly and annual estimates for a series of years. The research is also incorporating recent field observations that suggest in-plume losses of certain pollutants through chemical and transport processing, such as that suggested by recent research including the recent ITCT 2k2 field observations [cite the emails and our AGU abstract]. This research effort may provide a set of guidelines for modelers using global ship emission inventories, adjusting for the in-plume effects to produce more accurate assessments of the large-scale environmental impacts of ship emissions.