ANNEX 1

Information Responding to the Criteria in Appendix III to Annex VI

1 Introduction

The information in this Annex supports the proposal by the United States (U.S.) and Canada for the designation of an Emission Control Area (ECA) to prevent, reduce and control emissions of nitrogen oxides (NO_X), sulphur oxides (SO_X) and particulate matter (PM) from ships operating in specific portions of our coastal waters, as described below, pursuant to Regulations 13 and 14, and Appendix III to MARPOL Annex VI.

1.1 Countries Submitting this ECA Proposal

This proposal is submitted jointly by the U.S. and Canada. The U.S. and Canada have an obvious common interest in addressing emissions from ships operating off their coasts given their geographic proximity and the nature of their markets. The United States and Canada ask the Committee to consider this proposal at MEPC 59 and refer it for adoption by the Parties to Annex VI, meeting under the auspices of MEPC 60.

The U.S. is a Party to Annex VI, having deposited its instrument of ratification with the IMO on October 8, 2008. The Government of Canada is working toward ratification of Annex VI and will be submitting a short information paper to MEPC 59 to inform the committee of progress. It is hoped that Canada will have ratified Annex VI before the meeting of MEPC 59. However, if this is not the case, we believe the committee should consider this proposal at MEPC 59 recognizing that the proposed ECA would not be adopted prior to Canadian ratification.[D]

1.2 Criteria for Designation of an Emission Control Area

Pursuant to Annex VI, an ECA may be considered for adoption by the Organization if supported by a demonstrated need to prevent, reduce, and control air pollution from ships. Section 3 of Appendix III to Annex VI sets out the following eight criteria for designation of an ECA:

3.1.1 a clear delineation of the proposed area of application, along with a reference chart on which the area is marked;

3.1.2 the type or types of emission(s) that is or are being proposed for control (i.e. NO_X or SO_X and particulate matter or all three types of emissions);

3.1.3 a description of the human populations and environmental areas at risk from the impacts of ship emissions;

3.1.4 an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality,

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[D] We note there is precedent for such an approach. For example, at the time the North Sea SECA proposal was submitted to MEPC 44, only two of the seventeen submitting parties had ratified Annex VI. In fact, when the North Sea SECA was adopted, only 10 of the submitting parties had ratified.

human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified;

3.1.5 relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts;

3.1.6 the nature of the ship traffic in the proposed Emission Control Area, including the patterns and density of such traffic;

3.1.7 a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_X, SO_X and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI; and

3.1.8 the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.

Section 2 of this document provides information addressing the first three criteria. Sections 3, 4 and 5 provide information addressing the fourth criterion. Sections 6, 7, 8 and 9 provide information addressing the fifth, sixth, seventh and eighth criteria, respectively. It is respectfully submitted that this ECA proposal meets all of the above criteria.

2 Description of Area Proposed for ECA Designation

Criterion 3.1.1 *The proposal shall include a clear delineation of the proposed area of application, along with a reference chart on which the area is marked.*

Criterion 3.1.2 *The proposal shall include the type or types of emission(s) that is or are being proposed for control (i.e., SO_X and particulate matter or NO_X or all three types of emissions).*

Criterion 3.1.3 *The proposal shall include a description of the human populations and environmental areas at risk from the impacts of ship emissions.*

2.1 Proposed Area of Application

The area proposed for ECA designation is illustrated in Figure 2.1-1. The area of the proposed ECA includes waters adjacent to the Pacific coast, the Atlantic/Gulf coast and the Hawaiian Islands. The Pacific portion of the ECA is bounded in the north such that it includes the approaches into Anchorage, but not the Aleutian Islands or points north. It continues contiguously to the South including the waters adjacent to the Pacific coasts of Canada and the U.S., with its southernmost boundary where California meets the border with Mexico. The Atlantic/Gulf coast portion of the ECA is bounded in the West by the border of Texas with Mexico, and continues contiguously to the East around the peninsula of Florida and north up the Atlantic coasts of the U.S.

and Canada and is bounded in the north by the 60th parallel. The Hawaiian Islands portion of the ECA includes only the eight main[E] Hawaiian Islands.

In the defined area, the outer boundary of the proposed ECA is 200 nautical miles (nm) from the U.S. and Canadian territorial sea baselines, except that it will not extend into marine areas subject to the sovereignty, sovereign rights, or jurisdiction of any State other than the United States or Canada consistent with international law and is without prejudice to any undelimited maritime boundaries. The boundary of the proposed ECA is based upon emissions modelling, presented in Section 3 of this Annex. That modelling shows significant adverse effects on human health and the environment attributable to emissions from ships operating as far as 200 nm from the territorial sea baseline for all of the coasts included in the proposed ECA. Because the modelling we performed did not extend beyond 200 nm, we are not proposing to extend the ECA any further from the baseline at this time. Accordingly, while the proposal is based on health and environmental impacts and was not specifically developed to cover the U.S. and Canadian Exclusive Economic Zones (EEZ), the outer boundary of the proposed ECA is generally congruent with the outer boundary of the U.S. and Canadian EEZs. A detailed description of the ECA, including select coordinates, is provided in Annex 2 of this proposal and a chart is presented in Annex 3.

Not included in the proposed ECA are the Pacific U.S. territories, smaller Hawaiian Islands, the Aleutian Islands and Western Alaska, the U.S. territories of Puerto Rico and the U.S. Virgin Islands, and the U.S. and Canadian Arctic. The U.S. and Canada are not making a determination that areas not included in the present proposal suffer no adverse impact from shipping. Further information must be gathered to properly assess these areas, and if in the future such further information demonstrates a need for protection of other areas, the affected State(s) would submit a proposal for ECA designation of such areas.

Figure 2.1-1: Area Proposed for ECA Designation

[E] As used here, the main Hawaiian Islands are the populated islands of the Hawaiian Islands chain, including Hawaii, Maui, Oahu, Molokai, Nihau, Kauai, and Lanai, plus Kahoolawe, which is an uninhabited nature reserve.

2.2 Types of Emissions Proposed for Control

The U.S. and Canadian Governments propose designation of an ECA to control emissions of NO_X, SO_X and PM. As explained below, emissions of NO_X and SO_X are precursors to fine particulate matter and emissions of NO_X are also a precursor to ground level ozone. Section 4.1 of this Annex provides details on the health impacts associated with fine particulate matter and ground-level ozone. Section 5 provides details on the impacts to ecosystems of various forms of nitrogen- and sulphur-containing compounds, including NO_X, SO_X and PM.

2.2.1 SO_X and PM

Particulate matter is a generic term for a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM_{10} refers to particles less than or equal to 10 micrometers (μm) in aerodynamic diameter. $PM_{2.5}$ refers to fine particles, less than or equal to 2.5 μm in aerodynamic diameter. Inhalable (or "thoracic") coarse particles refer to those particles greater than 2.5 μm but less than or equal to 10 μm in aerodynamic diameter. Ultrafine PM refers to particles less than 100 nanometers (0.1 μm) in aerodynamic diameter.

Ambient fine particulate matter is composed of primary $PM_{2.5}$ (directly emitted particles) and secondary $PM_{2.5}$ (particles created through chemical and physical interactions of precursor pollutants). Of the precursor gases emitted by ships, SO_X and NO_X can directly lead to the formation of secondary $PM_{2.5}$. The majority of the PM associated with ships, both that which is directly emitted and that which is secondarily formed from ships' emissions of NO_X and SO_X, is in the fine particle size fraction.

It is highly beneficial, from a public health perspective, to control PM because even short-term exposures (hours to days) to ambient PM can cause coughing, difficulty breathing, changes in lung and heart function and premature death. The World Health Organization (WHO) has set air quality guidelines (AQG) for $PM_{2.5}$. Although scientists have not identified any ambient threshold for PM below which no damage to health is observed, the annual mean $PM_{2.5}$ guideline established by WHO is 10 $\mu g/m^3$ and the 24-hour mean $PM_{2.5}$ guideline is 25 $\mu g/m^3$.

2.2.2 NO_X

Anthropogenic emissions from industrial and transportation sectors as well as biogenic emissions generate the precursor air pollutants that lead to the photochemical formation of ground-level ozone or "smog." Ground-level ozone pollution is formed by the reaction of volatile organic compounds (VOCs) and NO_X in the atmosphere in the presence of heat and sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as on-road vehicles and non-road engines (including ships), power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources. As discussed in Section 8, governments in the U.S. and Canada have already imposed restrictions on ozone precursor and other emissions from a wide range of land-based industrial and transportation sources as well as consumer and commercial products.

The science of ozone formation, transport, and accumulation is complex (U.S. EPA, 2006). Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically would occur on a single high-temperature day. Ozone can be transported hundreds of kilometres downwind of precursor emissions, resulting in elevated ozone levels even in areas with low local VOC or NO_X emissions.

It is highly beneficial, from a public health perspective, to control ozone because exposure to ozone can cause throat irritation and make it more difficult to breathe deeply. Ozone can also aggravate asthma, leading to more asthma attacks. The WHO has set an air quality guideline for ozone of 100 $\mu g/m^3$, or approximately 50 ppb, for an 8-hour mean.

2.2.3 Other Forms of Pollutants

There are adverse human health effects caused by direct inhalation of SO_X or NO_X alone. These are described in Section 3.1.2 of the Information Document. However, due to the imprecise science of discerning those effects that are due solely to SO_X versus its PM derivatives (i.e. sulphate particles) or to NO_X versus its derivatives, ozone and PM, we do not separately quantify the human health impacts from exposure to direct SO_X and NO_X.

When considering adverse effects to the environment including ecosystems, it is relevant to discuss multiple forms of the regulated pollutants. Not only are there impacts to ecosystems from deposition of PM and ozone, nitric and sulphuric acids are also formed from NO_X and SO_X, respectively. Where this Annex describes impacts to ecosystems from sulphur and nitrogen, those terms are meant to include all forms of sulphur-containing or nitrogen-containing compounds, respectively.

Throughout this Annex, the need to prevent, reduce and control all three pollutants - NO_X, SO_X and PM - from ships operating in the proposed area is demonstrated.

2.3 Populations and Areas at Risk from Exposure to Ship Emissions

The U.S. and Canada, are among the world's largest countries, in terms of land area, with a combined length of oceanic coastline over 200,000 km. The landscape of our countries is widely varied. Many climate regions are represented, including sub-arctic, temperate, desert and sub-tropical. The land areas include vast mountain ranges, extensive river systems and expansive prairies. For example, the Rocky Mountains in the Western U.S. and Canada span more than 4,800 kilometres from northernmost British Columbia in Canada to New Mexico in the United States, and have peaks that reach as high as four kilometres. Also, the Jefferson-Missouri-Mississippi river system is among the largest in the world, with a length of 6,300 km. Further, our populations are highly urbanised; the U.S. and Canada have over 50 metropolitan areas (both inland and coastal) with populations greater than one million.

Over half of the population in U.S. and Canada resides along the Pacific and Atlantic coasts in centres of global commerce such as Vancouver, Los Angeles, Miami and New York. In 2000, the U.S. Census Bureau estimated that approximately 150 million people lived within U.S. coastal regions (about 53 percent of 280 million people total).[F] Current population projections estimate that by 2020, the U.S. population will grow to approximately 340 million (Woods and Poole, 2007) exposing more people to the risk of harm from ship emissions. In 2006, Statistics Canada estimated

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[F] U.S. Census Statistical Abstract. http://www.census.gov/compendia/statab/tables/08s0025.xls (accessed 12/11/08). Note that coastal regions, as defined by the National Oceanic and Atmospheric Administration, are 673 counties and equivalent areas with at least 15% of their land area either in a coastal watershed (drainage area) or in a coastal cataloging unit (a coastal area between watersheds).

the population of Canada to be approximately 31.5 million. Of that number, just over 20 million (>60 percent) live in coastal areas. By 2020, Canada's population is expected to grow to 36 million.

Because ship pollution travels great distances, much of the inland population will also benefit from the cleaner air delivered by this ECA. Pollution from ships can be transported hundreds of nautical miles over the ocean and/or hundreds of kilometres inland by the winds commonly observed offshore and over the U.S. and Canada. The figures presented in Section 3.3 depict the coastal and inland areas over which the emissions from ships are conveyed. Because these also tend to be areas that are heavily populated, this compounds the nature of the risk from such emissions.

In addition to broad exposure across much of the U.S., local populations are exposed more acutely. A preliminary study by the U.S. Environmental Protection Agency suggested that nearly 18 million people in the vicinity of 45 representative large U.S. ports are exposed to levels of PM from diesel engines including ships, which are substantially above those experienced further from these ports. This exposed population includes a higher than average proportion of low-income households and ethnic minorities (ICF, 2008).

2.4 Conclusion

Based on the information presented above, this proposal for an ECA fulfils criteria 3.1.1, 3.1.2 and 3.1.3 of MARPOL Annex VI, Appendix III.

3 Contribution of Ships to Air Pollution and Other Environmental Problems

Criterion 3.1.4 *The proposal shall include an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified.*

3.1 Synopsis of the Assessment

Criterion 3.1.4 calls for an assessment that is the heart of this proposal. For clarity, the information addressing this criterion is presented in a logical sequence beginning here in Section 3 and continuing in Sections 4 and 5 of this Annex. The emission inventory is presented first, in Section 3.2, and is derived from and builds on the shipping traffic information presented later in Section 7. It provides a solid foundation upon which the subsequent analyses are based. Modelled ambient concentrations of PM and ground-level ozone (smog formed from NO_X and other precursors) are presented below in Section 3.3, showing where and by how much we expect air quality to change due to emissions from ships, both for a business-as-usual scenario and with the proposed ECA. Section 4 builds on this by describing the human health impacts of populations living in the affected areas that are harmed by breathing this polluted air. Finally, the adverse impacts of ship emissions to ecosystems are described in Section 5. Each of these analyses is complex and involves some degree of uncertainty. The results presented are appropriate estimates generated using state-of-the-art methods, to assist decision-making regarding this proposal. Where the reader seeks additional details beyond what is described here, the Information Document is available for reference.

Ship traffic in the area that would be covered by the proposed ECA is substantial. The U.S. and Canada typically see over 93 thousand vessel calls at their ports annually. This shipping traffic occurs off of all of the coasts included in the proposed area. In addition, many more vessels operate in these areas that do not call on U.S. or Canadian ports, but instead are en route to Mexico or South America. Where these ships operate, they emit pollutants including NO_X, SO_X, and PM. To characterize these emissions, we created a detailed emission inventory that not only estimates total emissions, but also identifies where they occur. We estimate that, in 2020, ships operating within 200 nm of the coast would contribute 1.3 million tonnes of NO_X, 969,000 tonnes of SO_X, and 115,000 tonnes of PM to U.S. and Canadian emission inventories, at their current emissions performance. An ECA would reduce these emissions substantially.

Much of the ship traffic around the U.S. and Canada is upwind of, and in close proximity to, heavily populated areas collectively containing hundreds of millions of inhabitants. The analysis conducted for this proposal indicates that winds frequently blow onshore in all areas of the proposed ECA. Further, NO_X, SO_X and PM emitted from ships remain airborne long enough to be transported long distances across sea and land, adversely affecting large portions of the U.S. and Canada. Beginning with the detailed emission inventory, and including meteorological information described in Section 6, we modelled the impacts of ship emissions on air quality on land. The results of this modelling shows significant impacts on ambient emissions of ground level ozone (formed from NO_X) and on PM (including secondary PM formed from NO_X and SO_X) extending hundreds of kilometres inland, on all coasts.

Ship emissions contribute to a large number of adverse human health impacts in the U.S. and Canada, especially in densely populated coastal areas. Scientific studies have shown that both ambient $PM_{2.5}$ and ozone are associated with a broad array of adverse impacts that cause harm to human health and the environment. To quantify adverse health impacts of pollution from ships, we performed modelling that translates modelled air concentration estimates into health effects incidence estimates. Left at current performance levels, by 2020, pollution from ships off the U.S. and Canadian coasts is estimated to contribute up to 12,000 premature mortalities, 4,600 cases of chronic bronchitis, 12,500 hospital admissions and emergency room visits, 13,000 cases of acute bronchitis, and 6.5 million acute respiratory symptoms, in the U.S. and Canada combined. Our analysis shows that, with the implementation of the proposed ECA, as many as 8,300 lives will be saved and over three million people will experience relief from acute respiratory symptoms each year.

Emissions from ships also adversely impact sensitive environmental areas across the U.S. and Canada. These impacts widely affect terrestrial and aquatic ecosystems, including areas of natural productivity, critical habitats and areas of cultural and scientific significance throughout the U.S. and Canada.

The great distances that these pollutants travel suggest that emissions from ships operating further than 200 nm from all of the coasts in the proposed ECA may have significant impacts on land. However, because the benefits modelling we performed did not extend beyond 200 nm, we are not proposing to extend the ECA any further from the baseline at this time.

3.2 U.S. and Canadian Emissions Inventory Summary

Ships operating in the area described in Section 2.1 above contribute to air pollution that is harmful to human health and the environment. In this section, it is shown that air quality over large portions of the United States (U.S.) and Canada is adversely affected by NO_X, SO_X, and PM emissions from ships. The U.S. and Canada used well-known and accepted methods and assumptions to estimate emissions inventories from ships under two different 2020 scenarios: 1) continuation of current NO_X, SO_X and PM emissions performance, and 2) adoption of the proposed ECA requirements. The emissions inventories described below were used in the ambient air quality models described in Section 3.3.

Table 3.2-1 summarizes emissions inventories from ships in the U.S. and Canada for several pollutants, as well as their contribution to total emissions inventories from anthropogenic sources in 2020, under both scenarios. These data indicate that ships are an important contributor to total NO_X, SO_X, and PM emissions. The estimates reported in Table 3.2-1 are national estimates. Ship emissions can be a significantly higher proportion of total emissions within coastal areas. As seen in Table 3.2-1, the emission reductions associated with the ECA designation will be substantial, ranging from approximately 85,000 to 834,000 tonnes reduced, depending on the pollutant.

Table 3.2-1: Emissions Inventory Contribution of Ships in 2020 [a,c]

SOURCE CATEGORY	METRIC TONNES PER YEAR							
	2020 Current Performance			2020 with ECA				
	U.S.[b]	Canada	Total	U.S.[b]	Canada	Total	Tonnes Reduced	Percent Reduction
SO_X								
Commercial marine	841,000	128,000	969,000	131,000	5,000	136,000	834,000	86%
Marine % of all sources			10%			1%		
NO_X								
Commercial marine	1,110,000	176,000	1,286,000	866,000	127,000	993,000	294,000	23%
Marine % of all sources			10%			8%		
$PM_{2.5}$								
Commercial marine	100,000	15,000	115,000	25,000	5,000	30,000	85,000	74%
Marine % of all sources			3%			1%		

Notes:

[a] The ship inventories include emissions within 200 nautical miles of the U.S. and Canada, roughly equivalent to the Exclusive Economic Zone (EEZ).

[b] For this analysis, the U.S. commercial marine vessel emissions inventory does not include ships powered by "Category 1" or "Category 2" (i.e., <30 L/cyl) engines. These smaller engines are already subject to strict national standards affecting NO_X, PM, and fuel sulphur content.

[c] In 2020, only a portion of ships in the fleet will have been built since 2016, when ECA 'Tier III' NO_X limits must be met. Fleetwide NO_X reductions will likely continue for several years after 2020 as ships built since 2016 continue to come into service.

3.2.1 Emissions Inventory Modelling and Inputs for 2020 Current Performance Scenario

The modelling presented here focuses on the effect of shipping emissions and ECA controls in 2020. This year was chosen for a number of reasons. First, air quality modelling is complex and time consuming, and, as a result, is typically only performed for selected years. In addition to running spatial allocation, air quality, and benefit models, a detailed emission inventory must be developed to perform this air quality modelling. This detailed emission inventory is not only needed for ship emissions, but for all other sources that contribute to ambient air pollution in the U.S. and Canada. By choosing 2020, we were able to make use of information and tools that had already been developed for wider scale air pollution modelling efforts.

Although the 0.1 percent fuel sulphur requirement goes into place for all vessels operating in ECAs beginning in 2015, the use of 2020 as the analytic year will still provide a representative scenario for the impact of the 0.1 percent fuel sulphur requirement on human health and the environment. So the impacts of the fuel requirement in 2020 are expected to be the same as in 2015, with a small increase due to growth. With regard to the NO_X impacts, while 2020 will include five years of turnover to the Tier III standards, the long service lives of engines on ocean-going vessels mean that the fleet will not be fully turned over, with about one-third of the total fleet expected to be compliant with Tier III standards. Therefore the estimate benefits of the program would not be significantly different than if we had performed the analysis for 2016 when the Tier III NO_X standards begin. Note that the global fuel sulphur standard does not go into effect until 2020. We did not include this in the 2020 analysis, to provide a better estimate of benefits in the early (pre-2020) years of the program. In conclusion, the choice of 2020 as the analytic year provides a balance between modelling too early of a year where the Tier III NO_X standards may not yet apply and modelling too late of a year where there may be more uncertainty associated with projecting emissions into the future.

The emissions inventories contained in Table 3.2-1 were assembled using separate modelling platforms for the U.S. and Canada. Both are described below. A more complete description of the shipping traffic is provided in section 7.

The U.S. ship emissions inventory includes commercial marine vessels with “Category 3” (i.e., >=30 L/cyl) propulsion engines. Emissions from both propulsion and auxiliary engines on these vessels are included. The inventories are a combination of estimates for emissions in port and underway (or interport).

- The port emissions inventories were developed for 117 ports. These ports are the principal ports in the U.S. based on total freight tonnage.

- Emissions between ports (at sea) were based on the Ship Traffic, Energy, and Environmental Model (STEEM). STEEM includes a waterway network of shipping lanes based on 20 years of observed ship locations obtained from two global ship reporting databases: the International Comprehensive Ocean-Atmospheric Data Set (ICOADS), and the Automated Mutual-Assistance Vessel Rescue (AMVER) system. The ship movement information in STEEM was primarily obtained from the United States Army Corp of Engineers (USACE) entrance and clearance data, combined with ship attributes data from Lloyd’s Maritime Intelligence Unit.

The U.S. inventory was developed for a base year of 2002. Inventories for 2020 were then projected using regionally derived growth rates and emission factors. The growth rates are based on the expected demand for marine bunker fuels associated with the flow of commodities into and out of the U.S. Fuel consumption by trade route and commodity type were developed using an econometric model for commodity projections, along with ship and voyage characteristics. The overall growth rate is consistent with that presented by the IMO Secretary General’s Informal Cross Government/Industry Scientific Group of Experts.

The Canadian ship emissions inventory includes commercial marine vessels over 400 gross tons. Emissions from propulsion and auxiliary engines as well as boilers are included, during all modes of use. Ship movements were obtained from two Canadian Coast Guard databases: Information System on Marine Navigation (INNAV) and Vessel Traffic Operations and Support Systems (VTOSS). Similar to the U.S. methodology, STEEM was used in conjunction with data from Lloyd’s Marine Intelligence Unit. Emissions were estimated along the empirical ship routes by assigning emission factors, load factors, and other parameters based on vessel class and location.

A more detailed ship emissions inventory prepared by the Chamber of Shipping of British Columbia was used on Canada's Pacific coast. This inventory used vessel traffic data, engine and fuel information specific to each ship to estimate emissions from voyages on Canada's Pacific coast during a 12-month period in 2005-06 (Chamber of Shipping of B.C., 2007).

Moderate region-specific growth rates were used to project emissions to 2020. Despite recent shipping activity declines, the rates used still appear appropriate for long-term average growth over the period 2002-2020.

3.2.2 Emissions Inventory Development for 2020 ECA Performance Scenario

To estimate the impacts of the proposed ECA controls, NO_X, PM, and SO_X emissions were adjusted to account for the emission reductions associated with the ECA NO_X and SO_X/PM limits, for ships within the ECA. For NO_X, since the standards vary by model year, the NO_X adjustment accounts for the portion of the fleet subject to the ECA emission limits in 2020. PM and SO_X emissions were adjusted solely as a function of the fuel sulphur content, assuming the in-use fuel sulphur content met the ECA limit of 0.1 percent.

It is important to note that the ECA scenario assumes ships meet ECA limits the entire time they are within the ECA, according to the empirically determined vessel traffic and routing in the base year. That is, analyses of benefits or costs throughout this application do not assume ships reroute in a manner perpendicular to the ECA boundary; they assume ships maintain existing routing. We believe this is a reasonable assumption because it is unlikely that ships currently operating near the coast would reroute beyond 200 nm from the coast, due to the time and expense associated with the additional distances that would need to be travelled.

3.3 Ships' Contribution to Ambient Air Quality

As described in Section 2.2, emissions of NO_X, SO_X and PM contribute to ambient levels of ozone and $PM_{2.5}$. We focus on ozone and $PM_{2.5}$ in this section because these pollutants are ubiquitous and are linked with serious human health impacts. The discussions of ambient air quality and health and ecosystem effects, found in this section and in subsequent sections, are centred around two key concepts:

Ships' contribution: Emissions from ships at sea can travel hundreds of nautical miles over sea and can penetrate hundreds of kilometres inland. The emissions can contribute to ambient concentrations of air pollution or to adverse environmental impacts in the U.S. and Canada. To quantify these impacts air quality modelling was performed under two scenarios. Ships' contribution to a given air pollutant concentration or environmental impact was estimated by first modelling a scenario of expected 2020 ship activity levels with today's ship emissions performance (the 'current performance' scenario). The current performance scenario was then compared to a second scenario identical except for zero emissions from ocean-going ships. The difference between the scenarios provides an estimate of the air pollution or environmental impact attributable to ships. It is on this basis that this application makes assertions such as "*If ships were to maintain their current emissions performance, ships' contribution to x would be y% in 2020.*"

Benefits of ECA: Based on ships' contribution to ambient air quality, the impact of shipping emissions on human health and the environment may be estimated. ECA benefits were estimated by modelling a third scenario with expected 2020 ship activity levels, in which all ships within the ECA meet the ECA limits, and comparing that scenario to the first 'current performance' scenario described above. The difference between the scenarios provided an estimate of the air pollution or environmental impact reduction that will result from improving ship emissions from current performance to ECA standards. It is on this basis that this application makes assertions such as "*Reducing ship emissions from today's performance to ECA standards will improve x by y%.*"

3.3.1 Overview of Air Quality Modelling

The air quality modelling performed for this analysis makes use of the emissions inventories described in section 3.2. The results of the air quality modelling are subsequently used to predict effects on human health and the environment, as described in sections 4 and 5 respectively.

Both the U.S. Government and the Government of Canada conducted air quality modelling for $PM_{2.5}$ and ozone using state-of-the-art modelling techniques. The air quality models used by the United States and Canada simulated the multiple physical and chemical processes involved in the formation, transport, and deposition of fine particulate matter and ozone as well as related nitrogen and sulphur products (see Section 5 for details on modelling of nitrogen and sulphur deposition). The U.S. used the Community Multi-scale Air Quality (CMAQ) model and Canada used the AURAMS (A Unified Regional Air-quality Modelling System) model. AURAMS (Gong et al., 2006; Moran et al., 2007) and CMAQ (Byun and Schere, 2006) present the same level of science and completeness in their representation of the atmosphere and its chemical constituents although the parameters used to model specific atmospheric processes may differ in some cases. In addition, both of these air quality models are commonly used nationally and internationally. Additional detail regarding the modelling platform used by the U.S. is included in the Information Document.

3.3.2 Ships' Contribution to Ambient $PM_{2.5}$ and Ozone Air Pollution in the U.S.

Air quality modelling shows that emissions of SO_X, NO_X and direct $PM_{2.5}$ from ships have a significant impact on ambient $PM_{2.5}$ and ozone concentrations across the U.S. Because of the long distances that pollutants emitted into the atmosphere may travel, emissions from ships operating as far as 200 nm from all coasts adversely impact U.S. and Canadian populations and ecosystems. This section presents the projected contribution of ship emissions to total ozone and $PM_{2.5}$ levels across the U.S.

3.3.2.1 $PM_{2.5}$ Contribution

Figure 3.3-1 presents projected annual mean $PM_{2.5}$ levels for the U.S. in 2020 for the 'current performance' scenario. This includes $PM_{2.5}$ emissions from all sources, including mobile sources such as trucks, locomotives, and ships, other man-made sources such as power plants, industrial boilers and petroleum refineries, and natural sources such as wind-blown dust. As discussed in Section 8, Governments in the U.S. and Canada have already imposed restrictions on emissions of NO_X, SO_X, PM and other air pollutants, from a wide range of land-based sources. Most of the U.S. is projected to have annual average $PM_{2.5}$ levels between 5 and 12 $\mu g/m^3$ with a few areas having higher levels and some areas in the west having lower levels. Note that the WHO threshold, below which adverse impacts are still seen, is 10 $\mu g/m^3$. Figure 3.3-1 is useful as background information to help understand the upcoming Figures 3.3-2 and 3.3-9.

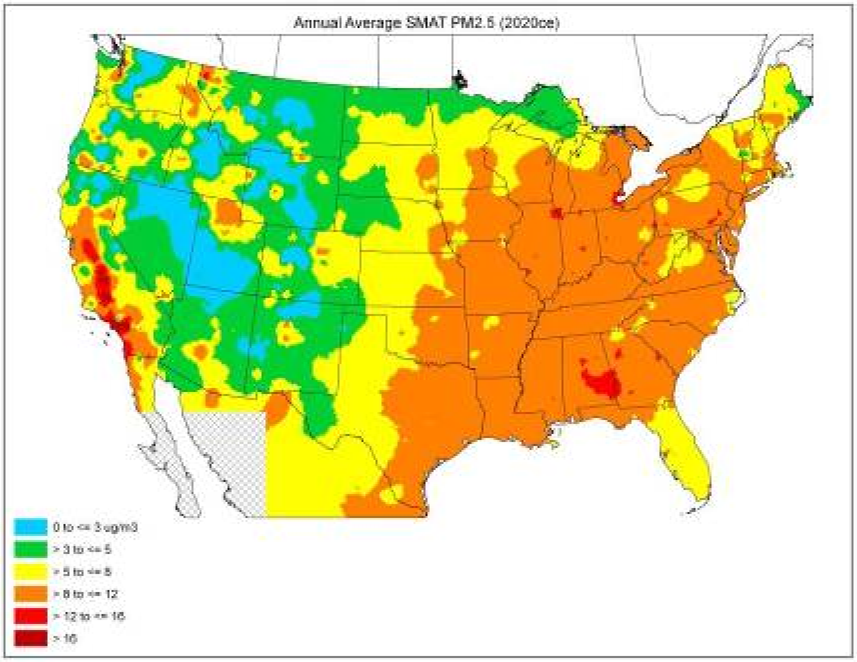

Figure 3.3-1 $PM_{2.5}$ Annual Mean Concentration for Current Performance Scenario in U.S. in 2020

Figure 3.3-2 illustrates the projected percentage contribution of emissions from ships to annual average $PM_{2.5}$ concentrations in 2020. To compare these emissions concentrations to where ships operate, see the shipping traffic patterns presented in Section 7. Because ship emissions can travel hundreds of nautical miles across open sea and hundreds of kilometres inland, it is difficult to separate out the particular coast from which the emissions originated since the emissions from all coasts mingle once on land. Not surprisingly, the contribution of ships to ambient $PM_{2.5}$ levels in coastal areas can be large.

The following geographic regions of the U.S. would receive the highest percentage contribution of ships to annual average $PM_{2.5}$ concentrations:

(1) <u>On the Pacific Coast</u>: the eastern half of Washington State ($PM_{2.5}$ contribution from shipping of 5 percent to more than 15 percent); southern California, including the Los Angeles to San Diego region ($PM_{2.5}$ contribution from shipping of 5 percent to more than 15 percent); the remaining Pacific coast including the entire coastal region of the State of Oregon and the entire central and northern coastal regions of the State of California ($PM_{2.5}$ contribution from shipping of 2 percent to 15 percent);

(2) <u>On the Gulf of Mexico</u>: from the southern reaches of the State of Texas through the States of Louisiana, Mississippi and the western coast of Florida ($PM_{2.5}$ contribution from shipping of 5 percent to 15 percent); the state of Alabama ($PM_{2.5}$ contribution of 2 percent to 5 percent); with more limited areas in the Louisiana delta region and Houston-Galveston region ($PM_{2.5}$ contribution of more than 15 percent); and

(3) <u>On the Atlantic Coast</u>: the entire eastern seaboard of the U.S. ($PM_{2.5}$ contribution of 2 percent to more than 15 percent); with the greatest contribution to $PM_{2.5}$ occurring from southern to central Florida ($PM_{2.5}$ contribution from shipping of more than 15 percent).

Equally important, the contribution of ships to ambient $PM_{2.5}$ levels inland is also significant. As can be seen in Figure 3.3-2, there is a continuous band of air quality impacts which extends inland for hundreds of kilometres on all the coasts to include the states of Montana, Idaho, Nevada, Utah, Wyoming, Colorado, Arizona, New Mexico, Oklahoma, Kansas, Arkansas, Missouri, Tennessee, Kentucky, West Virginia and Vermont.

In absolute terms the contribution from ships to annual average $PM_{2.5}$ concentrations is cause for concern and is projected to be greater than 3 $\mu g/m^3$ for highly populated portions of southern California, while both southern Louisiana and Florida are projected to show impacts greater than 1.5 $\mu g/m^3$.

This work indicates that ships contribute a large percentage of the ambient $PM_{2.5}$ across much of the western, southern and eastern U.S., thereby justifying the establishment of a SO_X/PM ECA in all three locations. This work also shows that significant amounts of PM travel well over 200 nautical miles over water and inland. For reference to the chart below, 200 nautical miles is roughly the length of the northern border of California, while significant PM impacts from ships are seen beyond Nevada. Section 3.3.4 addresses the impact of the proposed ECA on ambient $PM_{2.5}$ across the U.S.

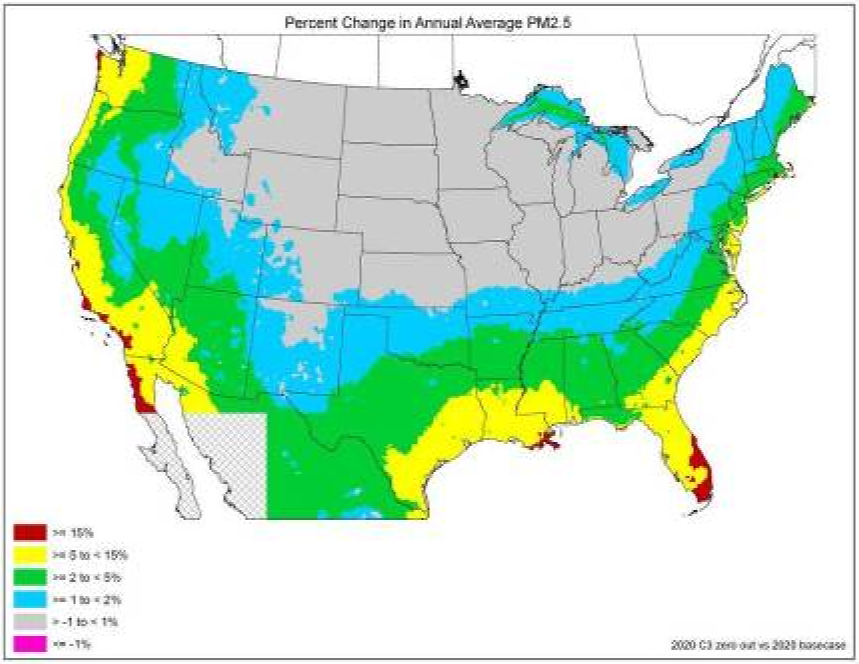

Figure 3.3-2 Percent Contribution of Ships to Annual Average $PM_{2.5}$ Concentrations in 2020

3.3.2.2 Ozone Contribution

Similarly, emissions of NO_X from ships have a significant impact on ozone concentrations both in coastal areas and deep inland. Figure 3.3-3 presents projected seasonal (defined as May-September) average daily 8-hour maximum ozone levels for the U.S. in 2020, for the ‘current performance’ scenario. Similar to Figure 3.3-1 above, this includes emissions from all sources. Concentrations over most of the U.S. are in the 40 to 50 ppb range with a few scattered areas being lower, 30 to 40 ppb, or higher, up to nearly 70 ppb. Note that the equivalent WHO guideline is approximately 50 ppb. Figure 3.3-3 is useful as background information to help understand the upcoming Figures 3.3-4 and 3.3-10.

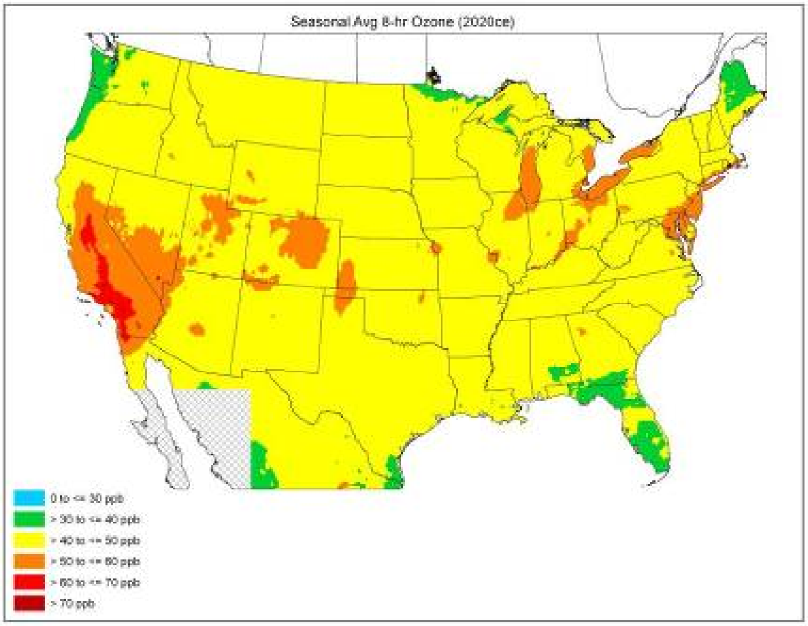

Figure 3.3-3 Projected Seasonal Average 8-hour Maximum Ozone Levels (ppb) for Current Performance Scenario in the U.S. in 2020

Figure 3.3-4 illustrates the projected percentage contribution of ships to 8-hour ozone concentrations in 2020. Because human exposure to ozone is a function of the temporal and spatial patterns of ambient concentrations of ozone in the atmosphere, the ozone-related health impacts analysis is sensitive to which ozone exposure metric we use in the health impact functions. For example, the 24-hour average is not the most relevant ozone exposure metric to characterize population-level exposure given that the majority of people tend to be outdoors during the daylight hours when concentrations are highest. Together, this means that the most biologically relevant metric is the 8-hour maximum standard. Similar to what was seen for $PM_{2.5}$, the contribution of ships to ozone levels in coastal areas can be large.

The following geographic regions of the U.S. would receive the highest percentage contribution of ships to 8-hour ozone concentrations:

(1) <u>On the Pacific Coast</u>: the eastern half of Washington State (percentage contribution of ships to 8-hour ozone concentrations of 5 percent to more than 15 percent); southern California, including the Los Angeles to San Diego region (percentage contribution of ships to 8-hour ozone concentrations of 5 percent to more than 15 percent); the remaining Pacific coast including the entire coastal region of the State of Oregon and the entire central and northern coastal regions of the State of California (percentage contribution of ships to 8-hour ozone concentrations of 2 percent to 15 percent);

(2) <u>On the Gulf of Mexico</u>: from the southern reaches of the State of Texas through the States of Louisiana, Mississippi, Alabama and Florida (percentage contribution of ships to 8-hour ozone concentrations of 5 percent to 15 percent); and

(3) <u>On the Atlantic Coast</u>: from the State of Florida in the southeast, through the States of Georgia, South Carolina, North Carolina (percentage contribution of ships to 8-hour ozone concentrations of 5 percent to 15 percent); the States Virginia, Maryland, and Delaware in the mid-Atlantic region to the States of Pennsylvania, New York, and all six States of New England in the northeast Atlantic region, an area stretching along the entire eastern seaboard of the U.S. for approximately two thousand miles and extending inland for hundreds of miles (percentage contribution of ships to 8-hour ozone concentrations of 1 percent to 15 percent).

Equally important, the impacts of ship emissions on ozone concentrations extend hundreds of kilometres inland to include states as far inland as Idaho, Nevada, Arizona, New Mexico, Oklahoma, Kansas, Missouri, Arkansas, Tennessee, Illinois, Indiana, Kentucky, and West Virginia. Many of these areas have relatively high background ozone levels.

In absolute terms, the contribution from ships is projected to be greater than 2 ppb, which is cause for concern, for most of the Gulf coast and South Atlantic regions as well as the Northeast coastal region.

These results indicate that controlling emissions from ships could have an important impact on ambient ozone concentrations, thereby justifying the establishment of a NO_X ECA in all three regions. Section 3.3.4 addresses the impact of the proposed ECA on ambient ozone across the U.S.

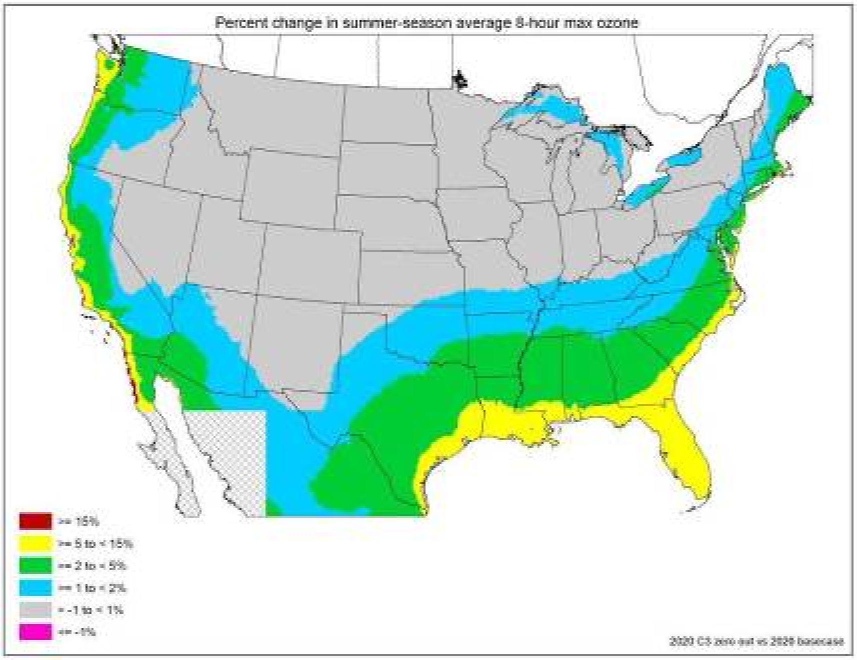

Figure 3.3-4 Percent Contribution of Ships to Seasonal Average Daily 8-hour Maximum Ozone Concentrations in 2020

The U.S. air quality maps above do not show Alaska and Hawaii. This is because the domain of the CMAQ model does not include these states. However ship emission inventories for Alaska and Hawaii were developed and are included in the totals presented in Section 3.1. Based on the inventory estimates, there are substantial ship emissions in the proposed ECA areas around Alaska and Hawaii. These are also the areas where most of the states' populations reside. Meteorological information in Section 6 suggests that these emissions affect air quality. The Canadian modelling described below suggests that there would be air quality improvements for Eastern Alaska along the Canadian border. Therefore, it is reasonable to expect ships are contributing to ambient air concentrations of ozone and $PM_{2.5}$ in Hawaii and Alaska, even though our modelling does not allow us to quantify these effects.

3.3.3 Ships' Contribution to Ambient Air Pollution in Canada

Air quality modelling performed for Canada also shows that emissions from ships contribute to ambient levels of ozone and $PM_{2.5}$ along the Atlantic and Pacific coastlines of Canada with shipping activity, and tens to hundreds of kilometres inland, depending on the pollutant and location.

Figure 3.3-5 presents projected annual mean $PM_{2.5}$ levels for 2015-2020[G] for the 'current performance' scenario. This includes $PM_{2.5}$ emissions from all sources. Densely populated and industrial areas of Canada would experience annual mean levels ranging between 5 and 10 $\mu g/m^3$. Outside urban centres, levels would range between 0 and 2 $\mu g/m^3$.

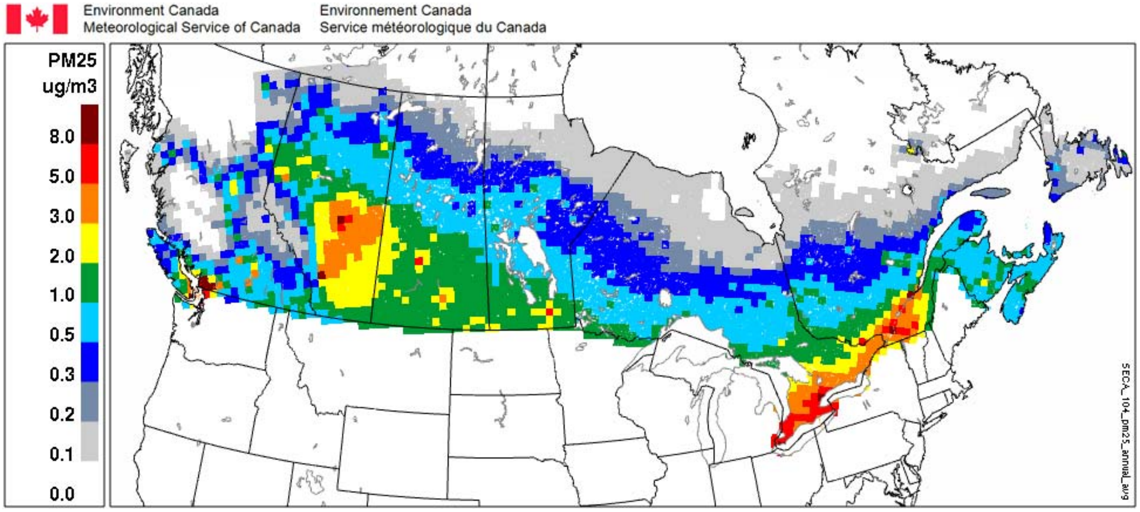

Figure 3.3-5: $PM_{2.5}$ Annual Mean Concentration for Current Performance Scenario in Canada in 2020.

As shown in Figure 3.3-6, at their current emissions performance, ships would contribute up to 15 percent to ambient $PM_{2.5}$ levels in 2020 in areas near the Pacific coast and between 5 to 15 percent in areas near the Atlantic coast.

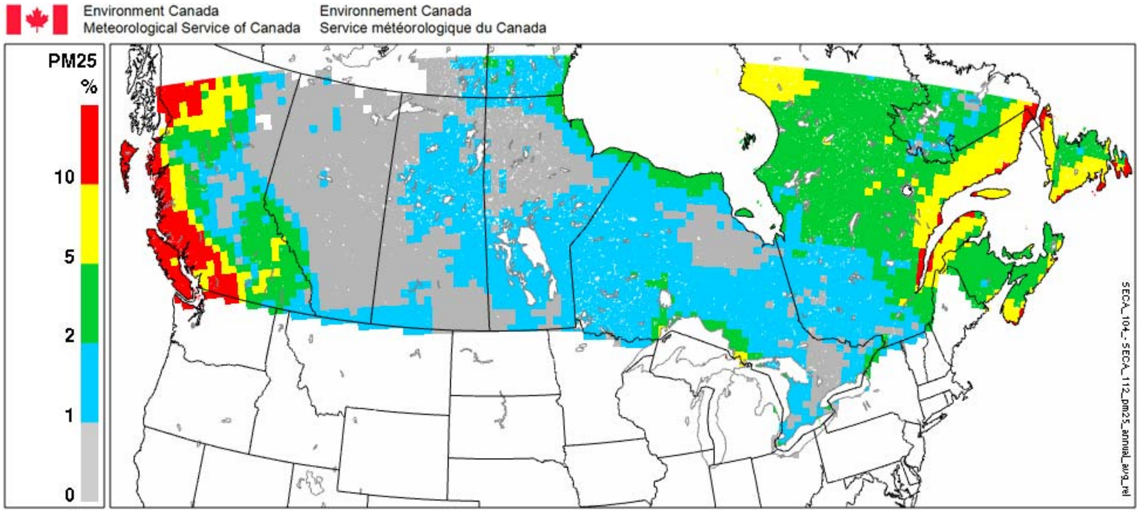

Figure 3.3-6: Ships' Contribution to Ambient $PM_{2.5}$ in 2020.

[G] Emissions from all sources except ships were projected to 2015. Ship emissions were projected to 2020.

Figure 3.3-7 presents the projected summertime (June, July and August) ozone levels for 2015-2020[H] for the 'current performance' scenario. Concentrations, in terms of the 8-hour average daily maximum, are expected to vary between 20 and 40 ppb. Densely populated and industrial areas of Canada, such as Metro Vancouver in southwestern British Columbia would experience ozone levels exceeding 60 ppb.

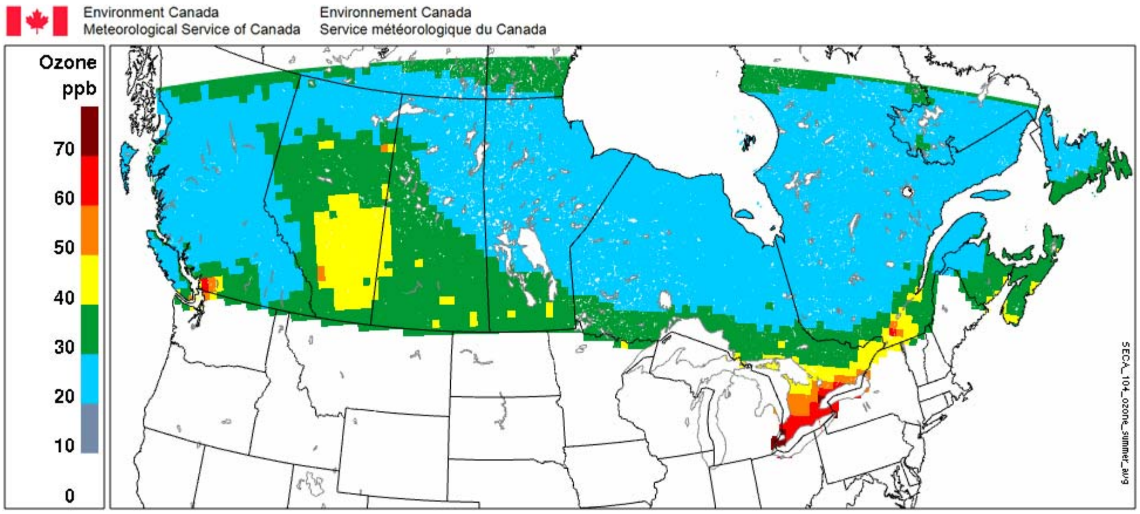

Figure 3.3-7: Summer (June, July, August) Average of Daily Maximum Based on 8-hr Rolling Average Ozone Concentration for Current Performance Scenario in 2020

Figure 3.3-8 illustrates the estimated contribution of ship emissions in 2020 to projected ambient ozone concentrations. The influence of ship emissions can clearly be seen in all Canadian coastal areas. Near the Pacific coast ship emissions would contribute between 5 and 15 percent, but the influence would extend inland over virtually all of British Columbia. Similar contributions are estimated in Nova Scotia, Newfoundland, and the north and south shores of the estuary and Gulf of St. Lawrence.

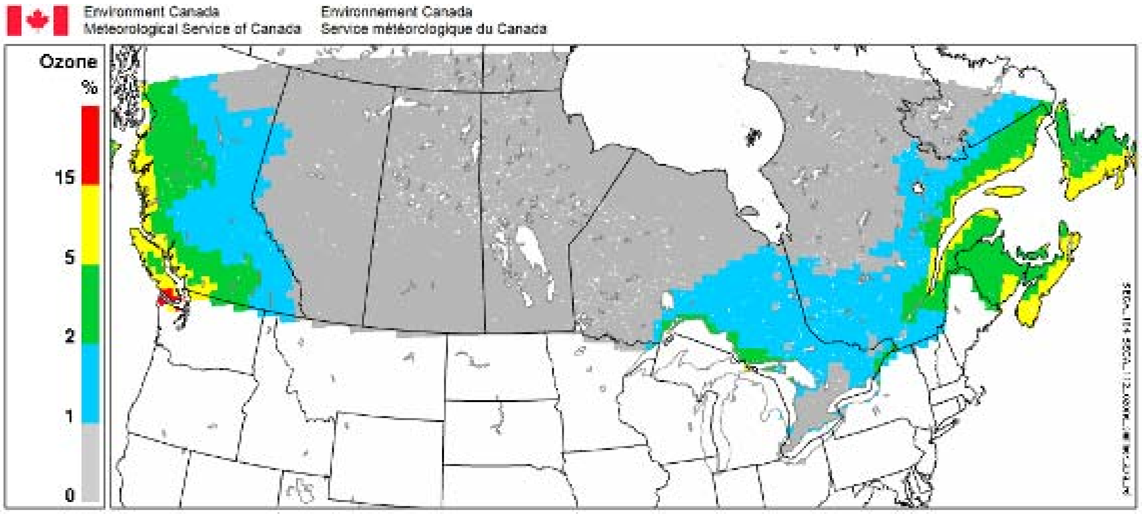

Figure 3.3-8: Ships' Contribution to Ozone in 2020.

[H] Emissions from all sources except ships were projected to 2015. Ship emissions were projected to 2020.

3.3.4 Improvement of Ambient Air Quality in the U.S. with the ECA

Figure 3.3-9 presents the projected percentage $PM_{2.5}$ improvements in 2020 if the proposed ECA were enacted out to 200 nm from the U.S. baseline. $PM_{2.5}$ improvements as high as 15 percent would occur in some coastal areas, for instance southern Florida and portions of the Atlantic coast, southern Louisiana and eastern Texas, and the western coast of the U.S., and significant $PM_{2.5}$ improvements would be continuous along all the coastlines. Additionally, $PM_{2.5}$ improvements of at least 1 percent would extend well inland including the cities of Birmingham, Alabama and Atlanta, Georgia, the northeast states, and eastern Washington and Oregon.

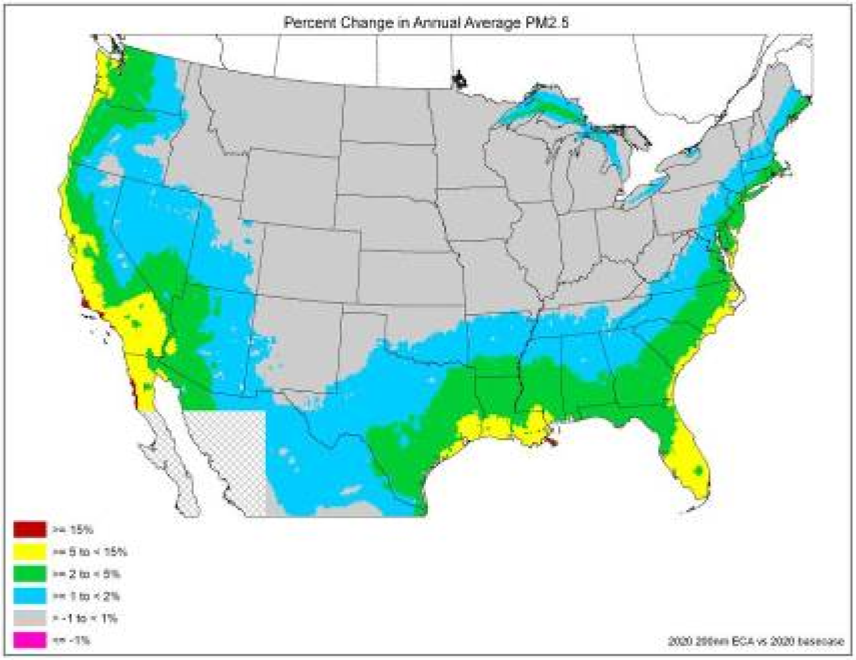

Figure 3.3-9 Percent Improvement in Annual Average $PM_{2.5}$ Concentrations in 2020 Resulting from the Application of the Proposed ECA

Figure 3.3-10 presents the projected percentage improvement in seasonal average daily maximum 8-hour ozone concentrations in 2020 if the proposed ECA were enacted. U.S. coastal areas would experience large ozone improvements of greater than 1 percent. In addition significant ozone improvements extend hundreds of kilometres inland including Arizona, Idaho, Missouri, Kentucky, Pennsylvania and New York as well. Areas like the Grand Canyon National Park, the Rocky Mountain Range, and the Great Smoky Mountains all would see significant ozone improvement.

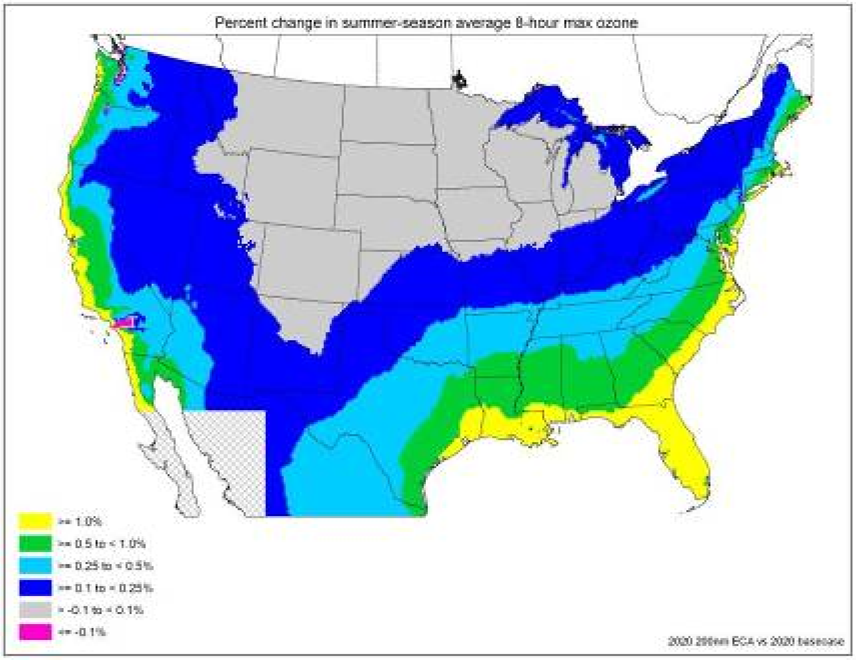

Figure 3.3-10 Percent Improvement in Average Daily Maximum 8-hour Ozone Concentrations in 2020 Resulting from the Application of the Proposed ECA

In conclusion, the U.S. coastline and much of the interior of the country will experience significant improvements in their air quality from the proposed ECA designation. These improvements are demonstrated for occur on all coasts included in the air quality model and are impacted by emissions reductions from shipping as far as 200 nautical miles from shore.

3.3.5 Improvement of Ambient Air Quality in Canada with the ECA

Improving ships' emissions from today's performance to the ECA standards will substantially improve ambient air quality in Canada as well. Projected reductions in $PM_{2.5}$ concentrations resulting from the proposed ECA are presented in Figures 3.3-11 and 3.3-12, for the regions of Canada that will benefit the most. The reduction will range from 5 percent to more than 10 percent in southwestern British Columbia. The Atlantic provinces of Canada will benefit by 2 to 5 percent.

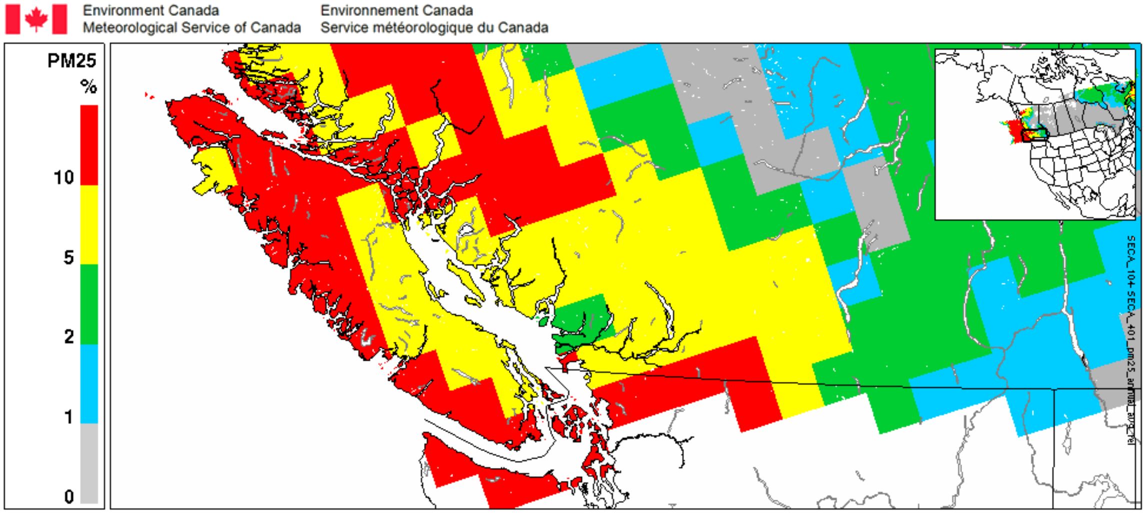

Figure 3.3-11: Reduction in Levels of Ambient $PM_{2.5}$ in 2020 from the Proposed ECA Compared to Current Performance, Zoomed Over Southwestern British Columbia.

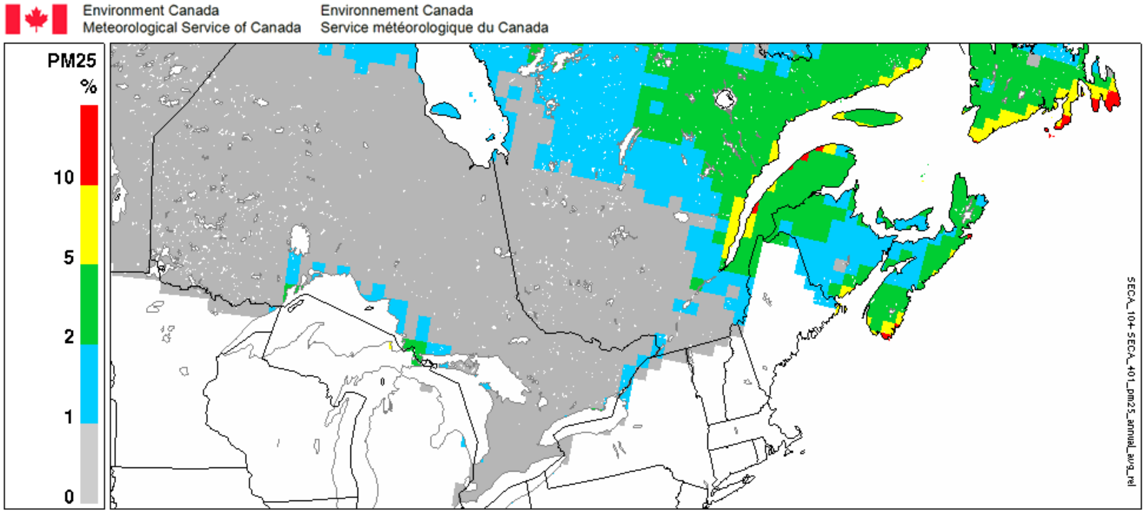

Figure 3.3-12: Reduction in Levels of Ambient PM$_{2.5}$ in 2020 from the Proposed ECA Compared to Current Performance, Zoomed Over Eastern Canada.

The corresponding projected ozone concentration reductions are presented in Figures 3.3-13 and 3.3-14. Reductions will range from 1 to 5 percent in most of the Metro Vancouver area, when averaged over the summer period, while the benefits in the Atlantic provinces of Canada would reach up to 2 percent. Ozone levels downwind of Vancouver are higher and of greater concern than ozone levels near its port.

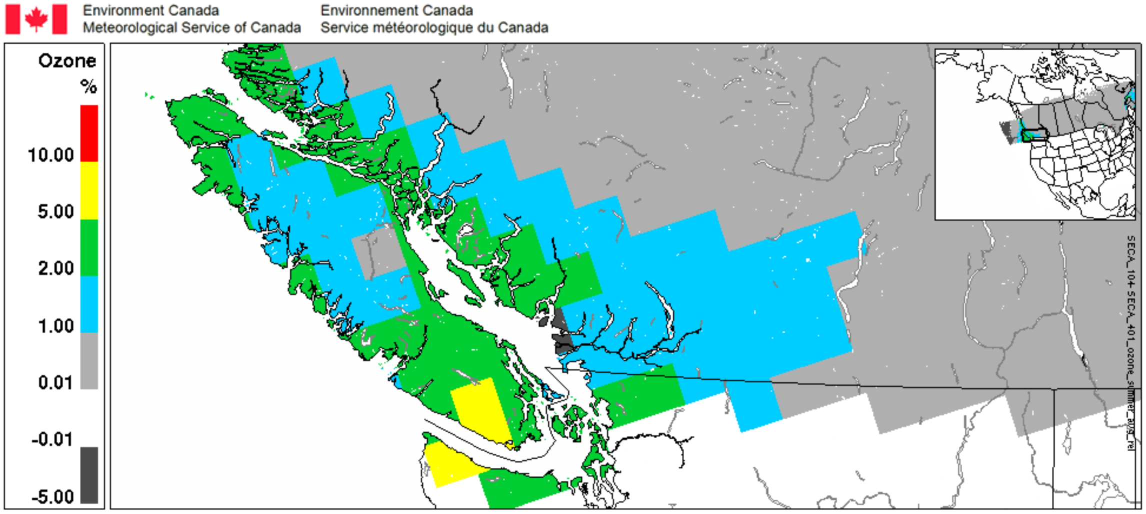

Figure 3.3-13: Reduction in Levels of Ozone in 2020 from the Proposed ECA Compared to Current Performance, Zoomed Over Southwestern British Columbia.

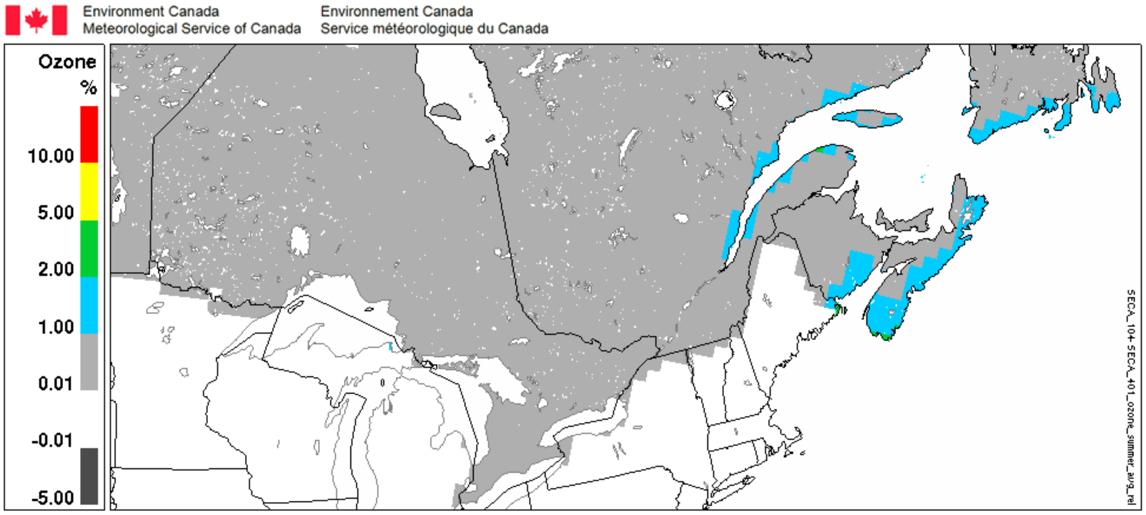

Figure 3.3-14: Reduction in Levels of Ozone in 2020 from the Proposed ECA Compared to Current Performance, Zoomed Over Eastern Canada.

3.3.6 Conclusions

Emissions from ships contribute a substantial fraction of ambient concentrations of ozone and $PM_{2.5}$ over large areas of the U.S. and Canada, including inland areas. As the above information shows, an ECA established under both regulations 13 and 14 is warranted. Reductions in NO_X emissions under regulation 13 would result in significant reductions in ozone and nitrate $PM_{2.5}$. Reductions in SO_X and PM under regulation 14 would result in significant reductions in $PM_{2.5}$ emissions. Improving ship emissions from today’s performance to ECA standards will deliver significantly improved ambient air quality in much of the U.S. and Canada. The improvement in ambient concentrations that will occur from this ECA designation will be a substantial achievement, and will deliver large health and ecosystem benefits as shown in Sections 4 and 5.

In this section of the application it was demonstrated that the emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution, as specified in the 4th criterion of MARPOL Annex VI, Appendix III, Section 3.

4 Impact of Emissions from Ships on Human Health

Criterion 3.1.4 This section builds on Section 3 in addressing criterion 3.1.4.

4.1 Health Effects Related to Exposure to Air Pollutants

Ships subject to the proposed ECA generate emissions that elevate on-land concentrations of harmful air pollutants such as $PM_{2.5}$ and ozone, as well as SO_X and NO_X. Human exposure to these pollutants results in serious health impacts such as premature mortality and aggravation of heart and lung disease. For this assessment, we quantify the health impacts associated with $PM_{2.5}$ and ozone formation, which includes the health impacts of SO_X in terms of their contribution to secondary $PM_{2.5}$ and nitrogen oxide compounds in terms of their contribution to secondary $PM_{2.5}$ and ozone. However, we do not separately quantify the health impacts from exposure to sulphur oxides and nitrogen oxides alone, due to the difficulty of discerning those effects that are due solely to SO_X versus its contribution to PM (i.e., sulphate particles) or effects due solely to NO_X versus its contribution to ozone and PM (i.e., nitrate particles for PM). For more information on the health effects specifically associated with sulphur oxides and nitrogen oxides, see Section 3.1.2 of the Information Document.

4.1.1 Nature of PM Health Effects

Scientific studies show ambient PM is associated with a series of adverse health effects. These health effects are discussed in detail in EPA's 2004 Particulate Matter Air Quality Criteria Document (PM AQCD) (U.S. EPA, 2004), and the 2005 PM Staff Paper (U.S. EPA, 2005)[I] as well as Canada's 1998 PM Science Assessment Document (SAD; Federal-Provincial Working Group on Air Quality Objectives and Guidelines, 1998) and 2005 update to the SAD (Health Canada, 2004a). Further discussion of health effects associated with PM can also be found in the Information Document.

Health effects associated with short-term exposures (hours to days) to ambient PM include premature mortality, aggravation of heart and lung disease (as indicated by increased hospital admissions and emergency department visits), increased respiratory symptoms including cough and difficulty breathing, changes in lung function, changes in heart rate rhythm, and other more subtle indicators of cardiovascular health (U.S. EPA, 2006a). Long-term exposure to $PM_{2.5}$ and sulphates has also been associated with mortality from cardiopulmonary disease and lung cancer, and effects on the respiratory system such as decreased lung function or increased respiratory disease. Studies examining populations exposed over the long term (one or more years) to different levels of air pollution, including the Harvard Six Cities Study and the American Cancer Society Study, show associations between long-term exposure to ambient $PM_{2.5}$ and both total and cardiopulmonary premature mortality (Dockery et al, 1993, Pope et al, 1995, and Krewski et al, 2000). In addition, an extension of the American Cancer Society Study shows an association between $PM_{2.5}$ and sulphate concentrations and lung cancer mortality (Pope et al, 2002).

In addition to the general PM health effects mentioned above, exposure to diesel particulate matter has also been associated with adverse health effects. Marine diesel engines emit diesel exhaust, a complex mixture which includes gaseous compounds and diesel particulate matter (DPM). The DPM present in diesel exhaust consists of fine particles (< 2.5µm), including a subgroup with a large number of ultrafine particles (< 0.1 µm). These ultrafine particles have a large surface area which makes them an excellent medium for adsorbing organic compounds and their small size makes them highly respirable. Many of the organic compounds present on the particles and in the gases are individually known to have mutagenic and carcinogenic properties. In EPA's 2002 Diesel Health Assessment Document (Diesel HAD), exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines (U.S. EPA, 2002). A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) have made similar classifications.

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern. Adverse pulmonary effects are well-quantified (Ishinishi et al, 1988), (Heinrich et al, 1995), (Mauderly et al, 1987), (Nikula et al, 1995). In addition to pulmonary effects, acute exposure to diesel exhaust has been associated with irritation of the eye, nose, and throat, respiratory

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[I] The PM NAAQS is currently under review and the EPA is considering all available science on PM health effects, including information which has been published since 2004, in the development of the upcoming PM Integrated Science Assessment Document (ISA). A first draft of the PM ISA was completed in December 2008 and was submitted for review by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board. Comments from the general public have also been requested. For more information, see http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201805.

symptoms (cough and phlegm), and neurophysiological symptoms such as headache, light-headedness, nausea, vomiting, and numbness or tingling of the extremities (U.S. EPA, 2002).

4.1.2 Nature of Ozone Health Effects

The health and welfare effects of ozone are well documented and are assessed in EPA's 2006 ozone Air Quality Criteria Document (ozone AQCD) (U.S. EPA, 2006b) and Staff Paper (U.S. EPA, 2007), as well as Canada's 1999 Ozone Science Assessment Document (SAD) (Federal-Provincial Working Group on Air Quality Objectives and Guidelines, 1999) and 2005 update to the SAD (Health Canada, 2004b). Ozone can irritate the respiratory system, causing coughing, throat irritation, and/or uncomfortable sensation in the chest. Ozone can reduce lung function and make it more difficult to breathe deeply; breathing may also become more rapid and shallow than normal, thereby limiting a person's activity. Ozone can also aggravate asthma, leading to more asthma attacks that require medical attention and/or the use of additional medication. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality. Short-term exposure to ambient ozone is likely to contribute to premature deaths (NRC, 2008). Animal toxicological evidence indicates that with repeated exposure, ozone can inflame and damage the lining of the lungs, which may lead to permanent changes in lung tissue and irreversible reductions in lung function. People who are more susceptible to effects associated with exposure to ozone can include children, the elderly, and individuals with respiratory disease such as asthma. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of particular concern.

The 2006 ozone AQCD also examined relevant new scientific information that has emerged in the past decade, including the impact of ozone exposure on such health effects as changes in lung structure and biochemistry, inflammation of the lungs, exacerbation and causation of asthma, respiratory illness-related school absence, hospital admissions and premature mortality. Animal toxicological studies have suggested potential interactions between ozone and PM with increased responses observed to mixtures of the two pollutants compared to either ozone or PM alone. The respiratory morbidity observed in animal studies along with the evidence from epidemiologic studies supports a causal relationship between acute ambient ozone exposures and increased respiratory-related emergency room visits and hospitalizations in the warm season. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and non-accidental and cardiopulmonary mortality.

4.2 Quantified Human Health Impacts from Exposure to Ship Emissions

This section presents the health impacts in the U.S. and Canada associated with emissions from ships, both in terms of the expected contribution of ship emissions to health impacts on land in 2020 if ships were to maintain their current emissions performance, and in terms of the reductions in health impacts that will occur by improving ship emissions to ECA standards within the proposed ECA.[J] Changes in ambient $PM_{2.5}$ and ozone that will result from the ECA are expected to improve human health in the form of avoided premature deaths and other serious human health effects, as well as other important public health and environmental effects.

[J] See definitions of "ships' contribution" and "benefits of ECA" in section 3.3.

4.2.1 U.S. Human Health Impacts

The U.S. government estimates that emissions from ships operating in the proposed ECA are responsible for up to 11,500 premature mortalities,[K] 12,000 hospital admissions,[L] 580,000 days of work lost, 810,000 days of missed school, and 5,700,000 days of restricted physical activity. The U.S. based its analysis on peer-reviewed studies of air quality and human health effects (see U.S. EPA, 2006 and U.S. EPA, 2008). These methods are described in detail in the related Information Document.

To model the U.S.-related ozone and PM air quality impacts of total shipping emissions, as well as the air quality improvements associated with the adoption of the ECA, the U.S. EPA used the Community Multiscale Air Quality (CMAQ) model (see Section 3). The modelled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program (BenMAP).[M] BenMAP is a computer program developed by the U.S. EPA that integrates a number of the modelling elements used in previous analyses (e.g., interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modelled air concentration estimates into health effect incidence estimates.

Tables 4.2-1 and 4.2-2 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states for two scenarios. The first scenario assesses the annual health impact of ship emissions if current emissions performance were to occur in 2020. The second scenario assesses the annual reduction of ship-related health impacts attributable to improving ship emissions to ECA standards in 2020.

We estimate that in 2020, PM from ships emitting at their current performance would be responsible for approximately 4,300 – 9,800 cases of premature mortality in adults (range based on the health impact function used – Pope et al., 2002 and Laden et al., 2006, respectively). Improving ship emissions to ECA standards will avoid between 3,400 – 7,800 premature deaths in 2020, a $PM_{2.5}$-related premature mortality risk reduction of approximately 79 percent. We also estimate that ships are responsible for a large number of $PM_{2.5}$-related morbidity impacts. For example, we estimate that in 2020, ships emitting at their current performance would be responsible for approximately 4,300 cases of chronic bronchitis, 8,900 non-fatal heart attacks, 5,600 hospital admissions and emergency room visits, 580,000 days of work lost, and 3,400,000 days of restricted physical activity. Improving ship emissions to ECA standards will result in the avoidance of 3,300 cases of chronic bronchitis, 7,200 non-fatal heart attacks, 4,400 hospital admissions and emergency room visits, 460,000 days of work lost, and 2,700,000 days of restricted physical activity. Again, improving to ECA standards will reduce the incidence of $PM_{2.5}$-related non-fatal health impacts by approximately 78 percent.

[K] Based on premature mortality estimates derived from Laden et al., 2006 for $PM_{2.5}$ and Levy et al., 2005 for ozone.

[L] Estimate includes cardiovascular and respiratory hospital admissions, as well as asthma-related emergency room visits.

[M] Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/benmodels.html.

Table 4.2-1. Estimated $PM_{2.5}$-Related Health Impacts Associated with Ships[a]

HEALTH EFFECT	2020 ANNUAL SHIP-RELATED INCIDENCE (CURRENT PERFORMANCE)	2020 ANNUAL REDUCTION IN SHIP-RELATED INCIDENCE WITH PROPOSED ECA
Premature Mortality[b]		
Adult, age 30+, ACS Cohort Study (Pope et al., 2002)	4,300	3,400
Adult, age 25+, Six-Cities Study (Laden et al., 2006)	9,800	7,800
Infant, age <1 year (Woodruff et al., 1997)	16	12
Chronic bronchitis (adult, age 26 and over)	4,300	3,300
Non-fatal myocardial infarction (adult, age 18 and over)	8,900	7,200
Hospital admissions - respiratory (all ages)[c]	990	780
Hospital admissions - cardiovascular (adults, age >18)[d]	2,100	1,600
Emergency room visits for asthma (age 18 years and younger)	2,500	1,900
Acute bronchitis, (children, age 8-12)	11,000	8,500
Lower respiratory symptoms (children, age 7-14)	84,000	66,000
Upper respiratory symptoms (asthmatic children, age 9-18)	62,000	48,000
Asthma exacerbation (asthmatic children, age 6-18)	79,000	62,000
Work loss days	580,000	460,000
Minor restricted activity days (adults age 18-65)	3,400,000	2,700,000

[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.

[b] PM-related adult mortality based upon the American Cancer Society (ACS) Cohort Study (Pope et al., 2002) and the Six-Cities Study (Laden et al., 2006). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf, (1997).

[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.

[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Similarly, ship emissions contribute to adverse health impacts associated with ozone exposure. For example, we estimate that in 2020, ships emitting at their current performance would be responsible for approximately 370 – 1,700 cases of premature mortality, depending on the health impact function, 6,600 hospital admissions and emergency room visits, 810,000 days of school absence, and 2,300,000 day of restricted physical activity. Improving to ECA standards will avoid between 61 – 280 premature deaths in 2020. Furthermore, it will result in the avoidance of 1,100 hospital admissions and emergency room visits, 130,000 days of school absence, and 360,000 days of restricted physical activity.

Table 4.2-2. Estimated Ozone-Related Health Impacts Associated with Ships[a]

HEALTH EFFECT	2020 ANNUAL SHIP-RELATED INCIDENCE (CURRENT PERFORMANCE)	2020 ANNUAL REDUCTION IN SHIP-RELATED INCIDENCE W/ 200NM ECA
Premature Mortality, All ages[b]		
Multi-City Analyses		
Bell et al (2004) – Non-accidental	370	61
Huang et al (2005) – Cardiopulmonary	620	100
Schwartz, (2005) – Non-accidental	560	93
Meta-analyses:		
Bell et al (2005) – All cause	1,200	200
Ito et al (2005) – Non-accidental	1,600	270
Levy et al (2005) – All cause	1,700	280
Hospital admissions- respiratory causes (adult, 65 and older)[c]	2,900	470
Hospital admissions -respiratory causes (children, under 2)	2,400	380
Emergency room visit for asthma (all ages)	1,300	210
Minor restricted activity days (adults, age 18-65)	2,300,000	360,000
School absence days	810,000	130,000

[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.

[b] Estimates of ozone-related premature mortality are based upon incidence estimates derived from several alternative studies: Bell et al. (2004); Huang et al. (2005); Schwartz (2005) ; Bell et al. (2005); Ito et al. (2005); Levy et al. (2005). The estimates of ozone-related premature mortality should therefore not be summed.

[c] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

As can be seen in Tables 4.2-1 and 4.2-2, ship emissions contribute to large numbers of adverse health impacts within the U.S. By designating an ECA, we estimate that by 2020, emission reductions will result in major reductions in health impacts associated with PM and ozone exposure.

4.2.2 Canadian Human Health Impacts

The Government of Canada estimated human health impacts using output from the air quality modelling described in Section 3, based on analysis of the peer-review literature detailing the associations between air pollution and adverse health effects. As in the U.S., the Government of Canada has embodied these relationships in a computer-based tool in order to facilitate analyses. The Air Quality Benefits Assessment Tool (AQBAT) uses atmospheric inputs combined with risk estimates from the peer-reviewed literature, as well as a number of population health statistics and other information, to estimate avoided adverse impacts resulting from air quality improvements. AQBAT is available for download from Health Canada, but the essential elements are discussed in documents dealing with the total burden of air pollution on human health in Canada (e.g. Judek et al., 2004).

Table 4.2-3 provides an overview of ships' contribution to 2020 $PM_{2.5}$ and ozone related health impacts, and the improvement that will result from improving ship emissions to ECA standards. About 60 percent of these health impacts take place in British Columbia.

Table 4.2-3: Ships' contribution to 2020 human health impacts, and improvement resulting from ECA[a] (combined $PM_{2.5}$ and ozone)

HEALTH EFFECT	2020 ANNUAL SHIP-RELATED INCIDENCE (CURRENT PERFORMANCE)	2020 ANNUAL REDUCTION IN SHIP-RELATED INCIDENCE WITH ECA
Mortalities	390	175
Hospital Admissions	99	34
Emergency Room Visits	320	95
Adult Chronic Bronchitis Cases	260	140
Child Acute Bronchitis Episodes	1,520	780
Asthma Symptom Days	76,000	19,000
Minor Restricted Activity Days	110,000	20,000
Restricted Activity Days	290,000	150,000
Acute Respiratory Symptom Days	790,000	280,000

Note: [a] rounded to two significant digits

4.3 Conclusion

As described above, emissions from ships contribute to a large number of adverse human health impacts. Designation of the proposed ECA would reduce the risk of premature mortality and contribute to the avoidance of many morbidity-related health impacts. Thus, this proposal for an ECA fulfils the human health portion of criterion 3.1.4 of MARPOL Annex VI, Appendix III.

5 Impact of Emissions from Ships on Ecosystems

Criterion 3.1.4 This section builds on Sections 3 and 4 in addressing criterion 3.1.4.

5.1 Overview of Deposition Resulting from Ship NO_X, SO_X and PM Emissions

Emissions from ships adversely impact sensitive ecosystems across the U.S. and Canada. These impacts will continue to grow in the coming decades, widely affecting terrestrial and aquatic ecosystems, including areas of natural productivity, critical habitats and areas of cultural and scientific significance throughout the U.S. and Canada.

Over the past two decades, the U.S. and Canada have undertaken numerous efforts to reduce NO_X, SO_X and PM emissions from a wide range of stationary and mobile sources which contribute to acidification and nutrient enrichment of many aquatic and terrestrial ecosystems across our two countries (see section 8 for a discussion of efforts to reduce NO_X, SO_X and PM emissions). SO_X and NO_X emissions from ships are carried over land and they and their derivatives (including PM and sulphur and nitrogen containing compounds) are deposited on surface waters, soils and vegetation. Importantly, air pollution can contribute a significant portion of the sulphur and nitrogen loading that an ecosystem receives. Some areas are more sensitive than others, and many have multiple stressors.

Analyses of long-term monitoring data for the U.S. show that deposition of both sulphur and nitrogen compounds has significantly decreased over the last 17 years although many areas continue to be negatively impacted by deposition. Between 1989-1999 and 2004-2006, both sulphur and nitrogen deposition was reduced in the U.S. but reductions were more substantial for sulphur compounds than for nitrogen compounds.[N] In the eastern U.S., where data is most abundant, total sulphur deposition decreased by 36 percent between 1990 and 2005 while total nitrogen deposition decreased by 19 percent over the same time frame. These decreases are the direct result of aggressive programs to reduce both SO_X and NO_X emissions from stationary sources and mobile sources across the U.S. and Canada. (Report on the Environment, EPA 2008)

Canadian actions to address domestic acidifying emissions first began in the 1980s when federal and provincial governments worked together through the Eastern Canada Acid Rain Program to reduce emissions of sulphur dioxide in Eastern Canada by more than 50 percent from 1980 levels. The Canadian governments continue to work cooperatively to address acid rain through measures such as *The Canada-Wide Acid Rain Strategy for Post-2000*, the long-term goal of which is to reduce acid deposition to below critical loads everywhere in Canada while keeping other areas (where acid rain effects have not been observed) clean. These efforts have been quite successful, with 2006 national SO_2 emissions totalling under 2 million tonnes (Mt), which is 38 percent below the 3.2 Mt/yr national cap first defined in the 1985 First UN-ECE Sulphur Protocol (cap for 1993 and beyond) and reiterated under the Canada-U.S. Air Quality Agreement (cap for 2000 and beyond). Like the results obtained by the U.S., emission reductions have translated into significantly reduced levels of deposition. Despite this, science shows that some regions are still receiving harmful levels of acid rain and some previously damaged ecosystems are not rebounding back to health as hoped (Environment Canada, 2005).

We are concerned that both current and future shipping activity will erode the environmental improvements that have been achieved over the last two decades in reducing sulphur and nitrogen deposition to many sensitive ecosystems throughout Canada and the U.S.

Air quality modelling conducted by the Government of the United States shows that if ships maintain their current emissions performance, by 2020, annual total sulphur and nitrogen deposition attributable to ships would range from 10 percent to more than 25 percent along the entire Atlantic, Gulf of Mexico, and Pacific coastal areas of the U.S. and this same level of adverse impact would extend inland for hundreds of kilometres.(See Figures 5-1 and 5-2) Of equal significance, ships would contribute to annual total sulphur and nitrogen deposition in the vast interior and heartland regions of the U.S. --contributing from 1 percent to 5 percent of all deposition in these regions. All these areas contain thousands of terrestrial and aquatic ecosystems which are sensitive to sulphur and nitrogen deposition and which are adversely impacted by ship emissions. Also in 2020, ships, at their current emissions performance, would contribute to visibility impairment in many urban areas located near deep water sea ports and in all 133 class I “federal areas” which are areas with special cultural and scientific significance such as national parks and wilderness areas. These areas are closely monitored by the U.S. government.

Similarly the Government of Canada predicts that if ships were to maintain their current emissions performance, in 2020 ships would significantly contribute to sulphur and nitrogen deposition in Canada, depending on the location. Ship emissions would contribute up to 90 percent of total sulphur deposition in southwestern British Columbia and up to 15 percent in other coastal areas. In the case of nitrogen deposition, ship emissions would contribute up to 60 percent in the southwest coast of British Columbia and up to 15 percent in remaining coastal areas.

[N] These numbers are generated by the U.S. national monitoring network and they likely underestimate total nitrogen deposition because NH_3 is not measured.

5.1.1 Environmental and Ecosystem Impacts and Areas at Risk

Emissions of NO_X, SO_X, and PM from ships increasingly contribute to the amount of sulphur and nitrogen being deposited in the U.S. and Canada. Deposition of certain nitrogen and sulphur compounds causes acidification, altering biogeochemistry and affecting animal and plant life in terrestrial and aquatic ecosystems across the U.S. and Canada. Prolonged exposure to excess sulphur and nitrogen deposition in sensitive areas acidifies lakes, rivers and soils. Increased acidity in surface waters creates inhospitable conditions for biota and affects the abundance and nutritional value of preferred prey species, threatening biodiversity and ecosystem function. Over time, acid deposition also removes essential nutrients from forest soils, depleting the capacity of soils to neutralize future acid loadings and negatively affecting forest sustainability. Major effects include a decline in some forest tree species, such as red spruce and sugar maple; and a loss of biodiversity of fishes, zooplankton, and macro invertebrates. The sensitivity of terrestrial and aquatic ecosystems to acidification from sulphur and nitrogen deposition is predominantly governed by geology. For a fuller understanding of the topics treated here, refer to the extended presentations in the Information Document accompanying this Annex.

The acidification of aquatic ecosystems poses a serious threat to the welfare of biological communities in the U.S. and Canada. Biological effects of acidification in terrestrial ecosystems are generally linked to aluminium toxicity and decreased ability of plant roots to take up base cations. Decreases in acid neutralizing capacity and pH and increases in inorganic aluminium concentration contribute to declines in zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems. For example, in the Adirondacks in the State of New York, the current rates of nitrogen and sulphur deposition exceed the amount that would allow recovery of the most acid sensitive lakes. (ISA NOx SOx; U.S. 2008) In the Southern Upland region of Nova Scotia, Atlantic salmon populations have declined to near extinction as a result of combined stress from acidification which reduces survival of young fish migrating from their natal rivers, and poor marine survival (Amiro et al., 2005). In the case of acidified rivers, pH recovery is not predicted to occur for another 50 to 70 years given the chemical complexity of these ecosystems (Clair et al., 2004). Acidification of Nova Scotia rivers has also been implicated in the decline of the endangered Atlantic whitefish (Bradford et al. 2005). Reductions in acidifying deposition to coastal and inland Nova Scotia will improve habitat availability and the prospects for salmon and whitefish recovery.

Areas most sensitive to terrestrial effects from acidifying deposition in the U.S. are depicted in Figure 5.1-1 and include forests in the Adirondack Mountains of New York State, the Green Mountains in the State of Vermont, the White Mountains in the State of New Hampshire, the Allegheny Plateau in the State of Pennsylvania, and high-elevation forest ecosystems in the southern Appalachians in the Southeast U.S. Many of the most acid sensitive surface waters in the U.S. are in the Northeast, mid-Atlantic and Southeast regions as can be seen in Figure 5.1-2. Additional waters sensitive to acidification include waters in the mountainous Western U.S and in the Pacific mountain regions stretching from the State of Washington down through the south central part of the State of California. (ISA NOxSOx; U.S. 2008)

In addition to the role nitrogen deposition plays in acidification, nitrogen deposition also causes ecosystem nutrient enrichment and eutrophication that alters biogeochemical cycles and harms animal and plant life such as native lichens and alters biodiversity of terrestrial ecosystems, such as grasslands and meadows. Nitrogen deposition contributes to eutrophication of estuaries and the associated effects including toxic algal blooms and fish kills.

There are a number of important quantified relationships between nitrogen deposition levels and ecological effects. Lichens are the most sensitive terrestrial taxa to nitrogen with clear adverse effects occurring at 3 kg N/ha/yr in the Pacific Northwest, southern California and Alaska. A United

States Forest Service study conducted in areas within the Tongass Forest in Southeast Alaska found evidence of sulphur emissions impacting lichen communities. The authors concluded that the main source of sulphur and nitrogen found in lichens from Mt. Roberts (directly north of the City of Juneau in southeastern Alaska) is likely the burning of fossil fuels by cruise ships and other vehicles and equipment in Juneau (Dilman et. al., 2007).

Lichen are an important food source for caribou and because of that, there is concern about the potential role damage to lichens may be having on the Southern Alaska Peninsula Caribou Herd, which is an important food source to subsistence based cultures (ADF&G, 2008). The herd has been decreasing in size, exhibiting both poor calf survival and low pregnancy rates which are typically a sign of dietary stress and there is now a complete hunting ban, including a ban on subsistence hunting.

Across the U.S. there are many terrestrial and aquatic ecosystems that have been identified as particularly sensitive to nitrogen deposition**.** Figure 5.1-3 depicts ecosystems potentially sensitive to aquatic nutrient enrichment while Figure 5.1-4 shows those areas potentially sensitive to terrestrial nutrient enrichment. The most extreme effects resulting from nitrogen deposition on aquatic ecosystems is severe nitrogen-loading which contributes to "hypoxic" zones devoid of life. Three hypoxia zones of special concern in the U.S. are the zones located in the Gulf of Mexico, the Chesapeake Bay in the mid-Atlantic region, and Long Island Sound, in the northeast U.S. (ISA NOx SOx; U.S. 2008)

The U.S. Government has recently compiled a comprehensive catalogue of U.S. ecosystems that are potentially sensitive to aquatic acidification, terrestrial acidification, aquatic nutrient enrichment, and terrestrial nutrient enrichment – all of which are outcomes of sulphur and nitrogen deposition (Risk and Exposure Assessment (REA) for the NO_X /SO_X; U.S. 2008). Figures 5.1-1 through 5.1-4 depict these sensitive ecological areas and their geographic distribution across the U.S. These sensitive areas experience the greatest ecological impacts associated with nitrogen and sulphur deposition resulting from shipping activity.

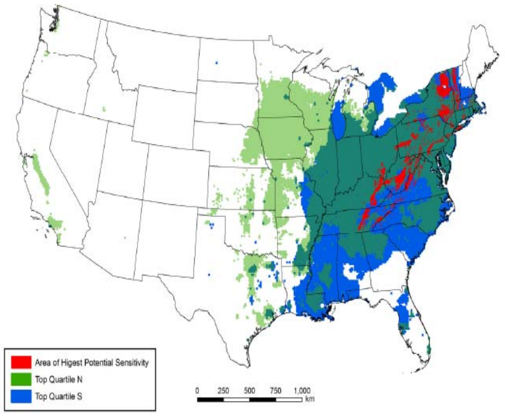


Figure 5.1-1 Areas Potentially Sensitive to Terrestrial Acidification

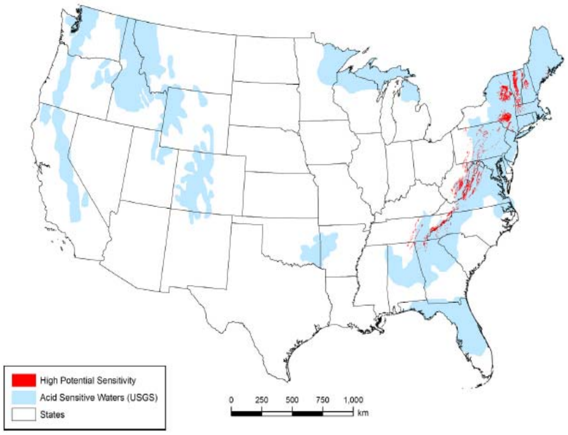


Figure 5.1-2 Areas Potentially Sensitive to Aquatic Acidification

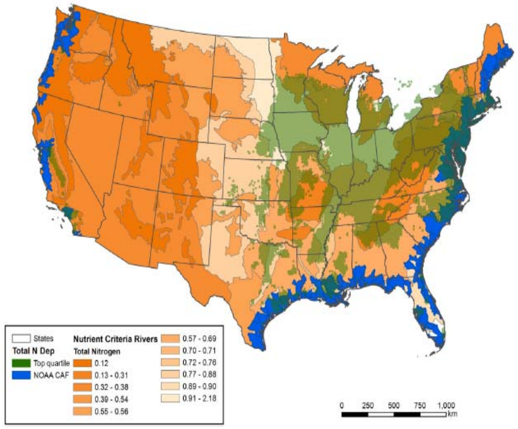


Figure 5.1-3 Areas Potentially Sensitive to Aquatic Nutrient Enrichment

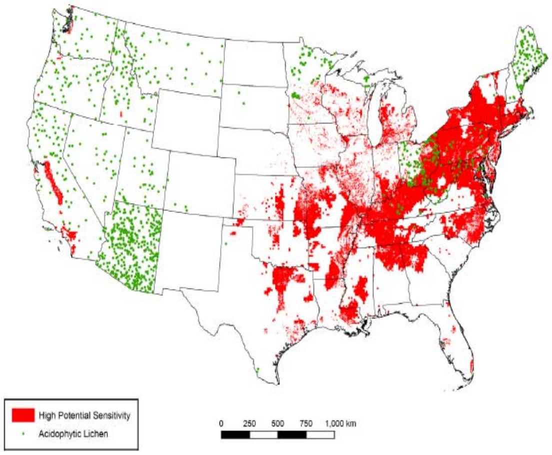


Figure 5.1-4 Areas Potentially Sensitive to Terrestrial Nutrient Enrichment

5.1.2 U.S. Modelling Results for Sulphur and Nitrogen Deposition

Modelling conducted by the U.S. government shows that if ships maintain their current emissions performance, in 2020, ships would add significant amounts to sulphur deposition in sensitive ecological areas across the U.S. ranging from 10 percent to more than 25 percent of total sulphur deposition along the entire Atlantic, Gulf of Mexico, and Pacific coastal areas of the U.S. and this same level of impact would extend inland for hundreds of kilometres effecting thousands of sensitive ecological areas and contributing to the serious problem of acidification in terrestrial and aquatic ecosystems (see Figure 5.1-5).

The following geographic regions of the U.S. and the sensitive ecosystems located within them would be most significantly exposed to sulphur deposition originating from ship emissions:

(1) On the Pacific Coast: the eastern half of Washington State (deposition contribution from shipping of 10 percent to more than 25 percent); southern California, including the Los Angeles to San Diego region (deposition contribution from shipping of 25 percent or more);

(2) On the Gulf of Mexico: the Galveston-Houston and the south Louisiana regions (deposition contribution from shipping of 17 percent to more than 25 percent); the entire State of Florida located in both the Gulf of Mexico and the Atlantic (deposition contribution from shipping of 20 percent); and

(3) On the Atlantic Coast: from the State of South Carolina in the southeast Atlantic region, through the States of Virginia, Maryland, and Delaware in the mid-Atlantic region to the States of Pennsylvania, New York, and all six States of New England in the northeast Atlantic region, an area stretching along the entire eastern seaboard of the U.S. for approximately two thousand miles and extending inland for hundreds of miles (deposition contribution from shipping of 10 percent to 20 percent).

Finally, ships would contribute to annual total sulphur deposition throughout the entire U.S. land mass, impacting terrestrial and aquatic ecosystems in the vast interior regions of the U.S. with ship-related sulphur deposition rates ranging from 1 percent to 5 percent.

Nitrogen deposition contributes to both acidification and nutrient over-enrichment. In 2020, ships would contribute a significant percentage of annual total nitrogen deposition to many terrestrial and aquatic areas within the U.S. that are potentially sensitive to excess nitrogen. Annual total nitrogen deposition from ships at their current emissions performance would range from about 9 percent to more than 25 percent along the entire U.S. Atlantic, Pacific and Gulf of Mexico coastal regions (see Figure 5.1-6).

The following geographic regions of the U.S. and the sensitive ecosystems located within them would be most significantly exposed to nitrogen deposition originating from ship emissions:

(1) <u>On the Pacific Coast:</u> the eastern half of Washington State (deposition contribution from shipping of 7 percent to more than 25 percent); the remaining Pacific coast including the entire coastal regions of the States of Oregon and California (deposition contribution from shipping of 5 percent to 17 percent);

(2) <u>On the Gulf of Mexico:</u> from the southern reaches of the State of Texas through the States of Louisiana, Mississippi, Alabama and Florida (deposition contribution from shipping of 7 percent to 25 percent), and more limited areas in the Louisiana delta region and Houston-Galveston region (deposition of more than 25 percent); and

(3) <u>On the Atlantic Coast:</u> the entire eastern seaboard of the U.S. with the greatest contribution to deposition occurring from southern to central Florida (deposition contribution from shipping of more than 25 percent).

Nitrogen deposition from ships would also extend inland for hundreds of kilometres impacting sensitive ecosystems at high levels. Finally, throughout the interior heartland regions of the U.S., ships would contribute to annual total nitrogen deposition--in the range of 1 percent to 5 percent by 2020.

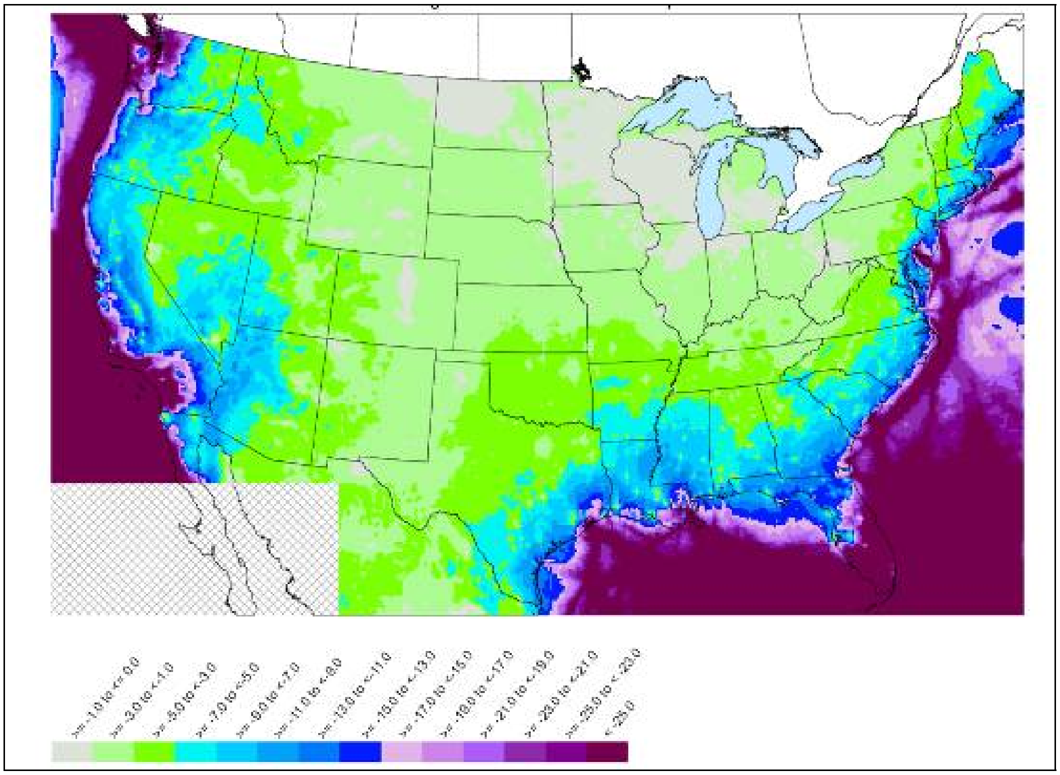


Figure 5.1-5 Percent Contribution of Ships to Annual U.S. Total Sulphur Deposition in 2020

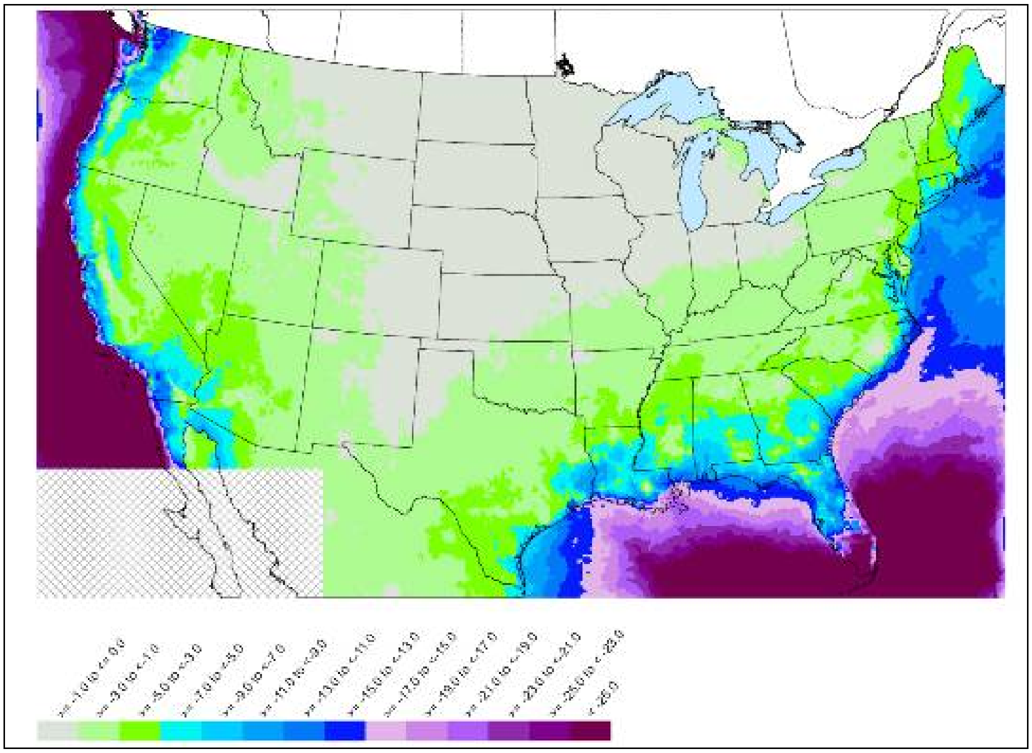


Figure 5.1-6 Percent Contribution of Ships to Annual U.S. Total Nitrogen Deposition in 2020

Adopting the proposed ECA will significantly reduce the annual total sulphur and nitrogen deposition occurring in sensitive U.S. ecosystems including forests, wetlands, lakes, streams, and estuaries. For sulphur deposition, reductions will range from 5 percent to 20 percent along the entire Atlantic seaboard and Gulf of Mexico coastal areas with higher levels of reduction – exceeding 25 percent, occurring in the near-land coastal waters of the U.S. In a few land areas on the Atlantic and Gulf coasts, such as the southern parts of the States of Louisiana, Texas, and Florida, 2020 sulphur deposition reductions will be much higher-over 30 percent. Along the Pacific coast, sulphur reductions will exceed 25 percent in the entire Southern California area, and the Pacific Northwest. All of these reductions will extend inland for hundreds of miles (For a map of 2020 sulphur reductions and additional information on the impacts of the proposed ECA on U.S. sulphur deposition see the Information Document accompanying this Annex)

Overall, nitrogen deposition reductions in 2020 resulting from the proposed ECA in 2020 will not be as large as for sulphur. Notwithstanding, there are still substantial benefits to be gained thus justifying the establishment of an ECA for NO_X. Reductions will range from 3 percent to 7 percent along the entire Atlantic, Pacific and Gulf coasts, and as with sulphur, these reductions will extend inland for hundreds of miles. As with sulphur, a few areas such as the southern parts of the States of Louisiana, Texas, and Florida will experience larger reductions of nitrogen up to 9 percent. The Pacific coastal waters will see higher nitrogen reductions exceeding 20 percent in some instances. (See the Information Document for a map and additional information on nitrogen deposition impacts)

5.1.3 Canadian Modelling Results for Sulphur and Nitrogen Deposition

The air quality modelling described in Section 3 was also used to quantify deposition of sulphur and nitrogen across Canada. Taking into account reductions in land-based emissions, and using combined modelling of atmospheric, aquatic and terrestrial systems, the Government of Canada predicts that if ships were to maintain their current emissions performance, in 2020 ships would significantly contribute to sulphur and nitrogen deposition in Canada, depending on the location. Ship emissions would contribute up to 90 percent of total sulphur deposition in southwestern British Columbia and up to 15 percent in the remaining coastal areas (Figure 5.1-7). In the case of nitrogen deposition, ship emissions would contribute up to 60 percent in the southwest coast of British Columbia and up to 15 percent in the remaining coastal areas (Figure 5.1-8).

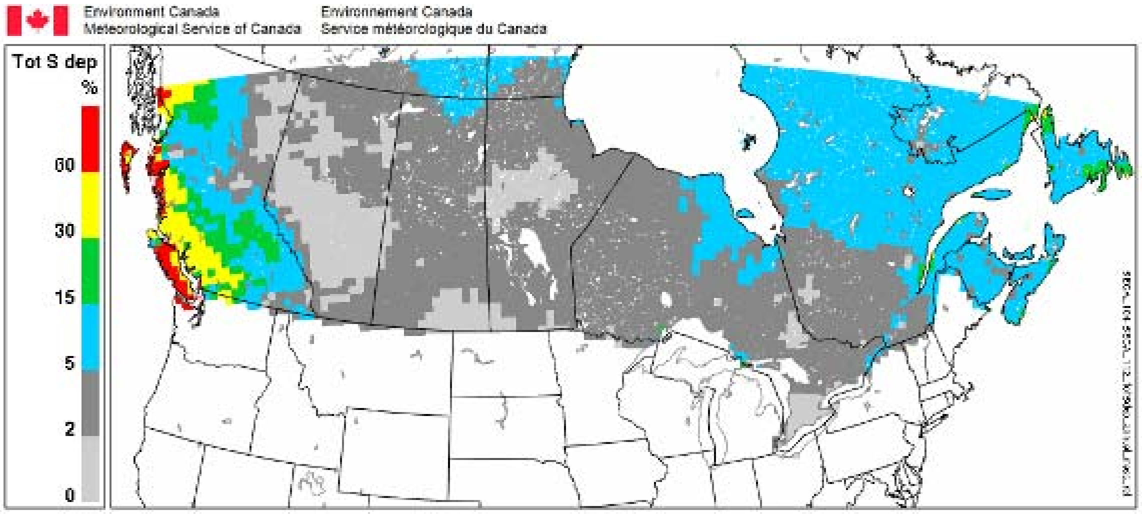


Figure 5.1-7: Ships' Contribution to Sulphur Deposition in 2020 at Current Emissions Performance.

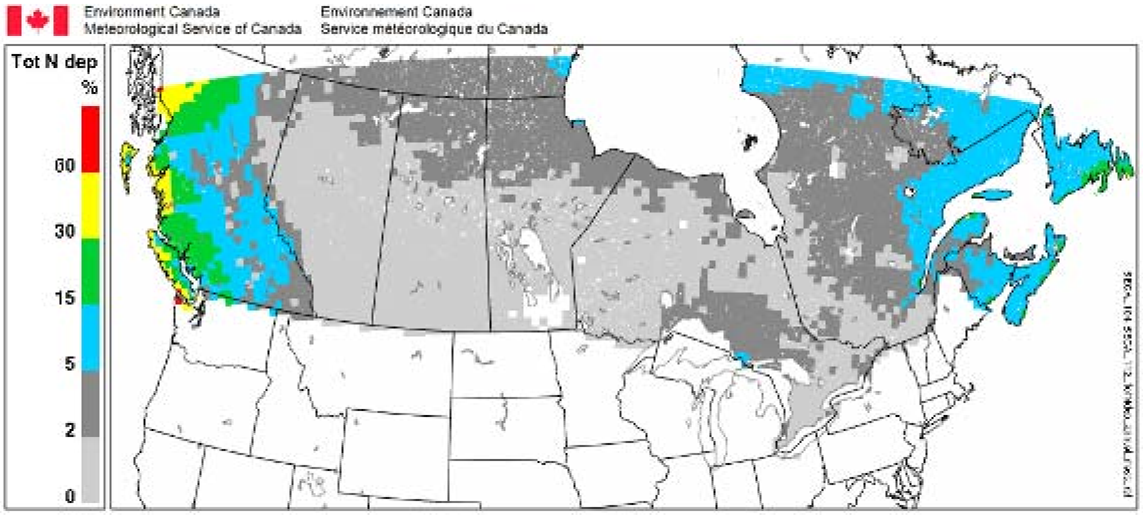


Figure 5.1-8: Ships' Contribution to Nitrogen Deposition in 2020 at Current Emissions Performance.

Improving ship emissions from current performance to ECA standards will result in declines in both total sulphur and total nitrogen deposition over Canada in the year 2020. Reductions in total sulphur deposition are estimated to be up to 60 percent in the Lower Fraser Valley and reaching 90 percent on Vancouver Island in British Columbia. Reductions of up to 30 percent will result along the Nova Scotia coast and the Gulf of St. Lawrence. The ECA will all but eliminate ships' contribution to sulphur deposition. For total nitrogen deposition, reductions will primarily occur in southwestern British Columbia, up to 15 percent.

5.1.4 Exceedances of Ecosystem Critical Deposition Loads in Canada Resulting from Ship Emissions

As presented in section 5.1.3, emissions of SO_X and NO_X from ships contribute to the amount of sulphur and nitrogen being deposited and entering Canada's terrestrial and aquatic ecosystems. Excess deposition is considered to be any amount that exceeds the critical load, which is the amount an ecosystem can withstand over the long-term before it is significantly damaged. In order to protect the long-term sustainability of ecosystems, it is important to maintain sulphur and nitrogen deposition below this threshold.

Different ecosystems have different amounts of deposition they can receive without harm (critical loads). When deposition exceeds these critical loads over a prolonged period of time, impacts to ecosystems occur. The contribution of ship emissions would result in many areas exceeding their critical load. Using the same modelling approach described in section 3, the Government of Canada predicts that if ships maintain their current emissions performance, by 2020 they would be contributing to sulphur and nitrogen deposition as high as 30 percent of the excess amount across southern New Brunswick, and southwestern British Columbia[O]. In addition, ships would be responsible for all the excess amount of sulphur and nitrogen deposition entering some ecosystems in parts of southwestern British Columbia (near the Pacific Ocean) and the Atlantic provinces (Figure 5.1-9 – red squares).

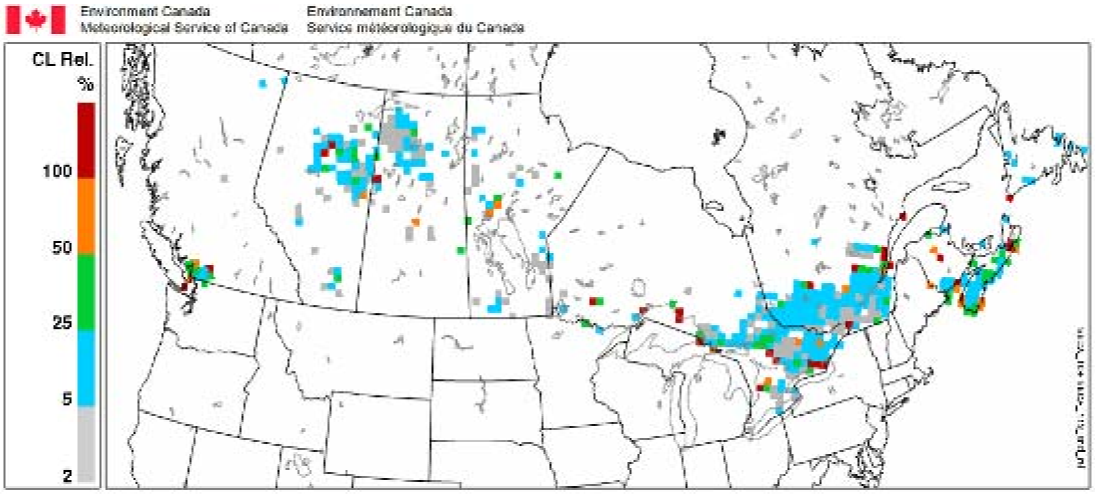


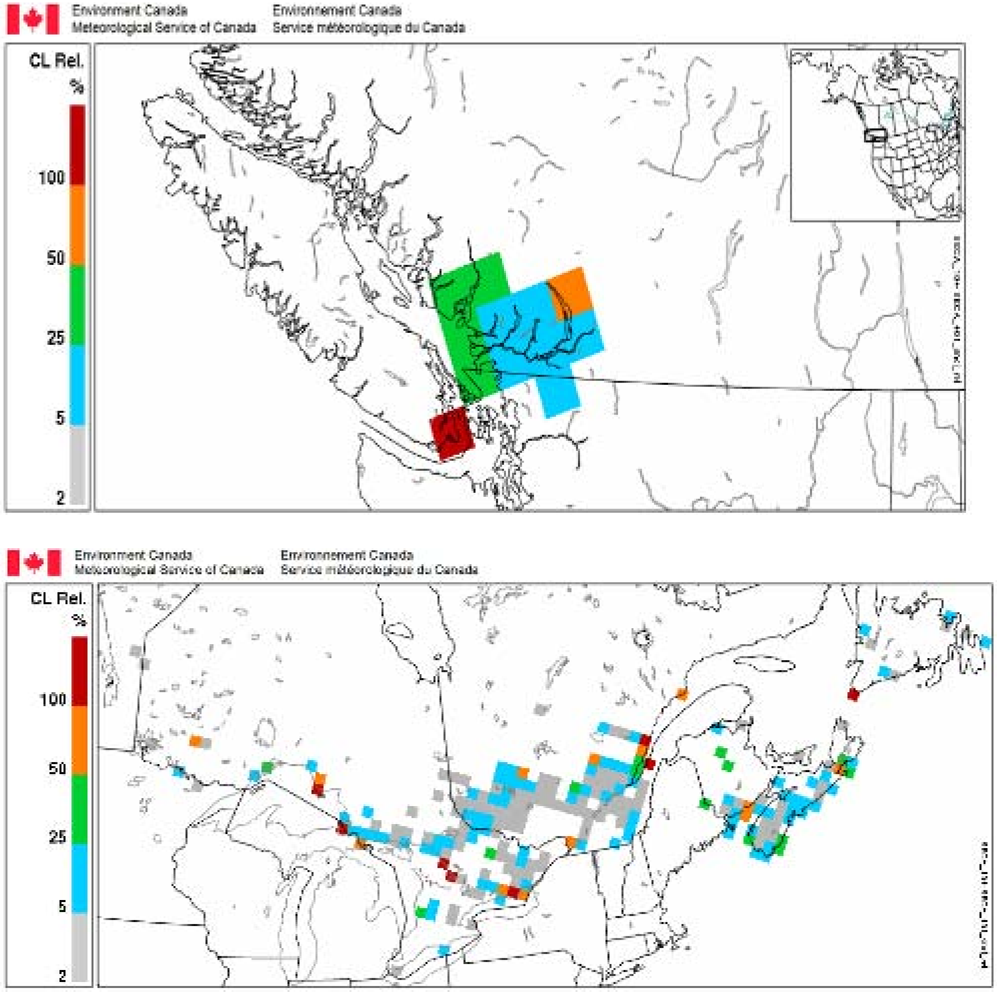
Figure 5.1-9 Ships Contribution to Sulphur and Nitrogen Deposition as a Percent of the Excess Deposition (Exceedance of the Critical Load) Across Canada in 2020.

Improving ship emissions from current performance to ECA standards will significantly reduce the excess total sulphur and nitrogen deposition in many Canadian sensitive ecosystems (Figures 5.1-10). For example, it will result in a 19 percent reduction in excess total sulphur and nitrogen deposition in southwestern British Columbia and an 11 percent reduction in New Brunswick. Most importantly, it will eliminate excess deposition over an area of ~13,500 km^2 across Canada.

[O] For example: In an area with total deposition of 1,100 units/ha/yr and a critical load of 1,000 units/ha/yr, the excess amount is 100 units/ha/yr. If ships contribute 140 units/ha/yr of the 1,100 units/ha/yr, then they contribute an amount equal to 140% of the excess amount. If they contribute 5 units/ha/yr then they contribute an amount equal to 5% of the excess amount.

The elimination of excess sulphur and nitrogen deposition in these areas will also help maintain the health and diversity of aquatic biological communities and the long-term sustainability of forest ecosystems in non-acidified areas. In already affected areas, it will increase the likelihood that ecosystems recover to a healthy state, although this will probably differ from their original pre-acidification state.

The above estimated impacts include only lakes and upland forest soil areas of Canada for which a critical load has been established based on available information and not inclusive of every lake and every forest soil type that may be sensitive to acid deposition. They may therefore underestimate the potential for acid deposition damage.



Figures 5.1-10 Percent Reduction in Excess Sulphur and Nitrogen in Southwestern British Columbia (top), and the Atlantic Coast (bottom), for the Proposed ECA Compared to Current Ship Emissions Performance.

5.2 Impacts Associated with Deposition of $PM_{2.5}$ and Air Toxics

ECA controls, particularly those that will reduce SO_X emissions are expected to substantially reduce $PM_{2.5}$ emissions from ships. Ecological responses to $PM_{2.5}$ are determined by both the atmospheric concentration of these particles as well as the mix of compounds that make up the particles (e.g. sulphate, nitrate, metals, organic compounds). Direct effects of vegetation are mostly attributed to injury to the leaf surface and may include abrasion of foliar wax, reduction in photosynthesis through shading, and foliar absorption of trace elements. Most vegetation responses to PM, however, occur indirectly via changes to soil quality (e.g. changes in soil pH, alteration of nutrient cycling, metal accumulation) due to atmospheric deposition (Grantz et al., 2003).

Ship emissions of $PM_{2.5}$ contain small amounts of metals—nickel, vanadium, cadmium, iron, lead, copper, zinc, aluminium (Agrawal, H. et al; Atmospheric Environment 2008; Isakson et al., 2001; Miller, W., et al., 2008). Investigations of trace metals near roadways and industrial facilities indicate that a substantial burden of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel are directly toxic to vegetation under field conditions (PM AQCD; U.S. EPA 2004). While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment.

Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline (Gawel *et al*., 1996). This correlation was further explored in high elevation forests in the northeast U.S. and the data strongly imply that metal stress causes tree injury and contributes to forest decline in the northeast (PM AQCD; U.S. EPA 2004). Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops. As the fallen leaves decompose, the heavy metals are transferred into the soil (Cortufo *et al*., 1995; Niklinski *et al*., 1998).

Ships also emit air toxics, including polycyclic aromatic hydrocarbons (PAHs) -- a class of polycyclic organic matter (POM) that contain compounds which are known or suspected carcinogens. Since the majority of PAHs are adsorbed onto particles less than 1.0 µm in diameter, long range transport is possible. Particles of this size can remain airborne for days or even months and travel distances up to 10,000km before being deposited on terrestrial or aquatic surfaces (PM AQCD; U.S. EPA 2004). Atmospheric deposition of particles is believed to be the major source of PAHs to the sediments of Lake Michigan, Chesapeake Bay, Tampa Bay and other coastal areas of the U.S. (Dickhut *et al*., 2000; Simcik *et al*., 1996; Simcik *et al*., 1999; Poor *et al*., 2002; Arzavus *et al*., 2001). PAHs tend to accumulate in sediments and reach high enough concentrations in some coastal environments to pose an environmental health threat that includes cancer in fish populations, toxicity to organisms living in the sediment and risks to those (e.g., migratory birds) that consume these organisms (Simcik *et al*., 1996; Simcik *et al*., 1999). PAHs tend to accumulate in sediments and bioaccumulate in fresh water, flora and fauna. Reduction in PM emissions from ships would reduce the long range transport of air toxics.

5.3 U.S. Visibility Impacts

Emissions from ships contribute to poor visibility in the U.S. through their primary $PM_{2.5}$ and NO_X emissions (which contribute to the formation of secondary $PM_{2.5}$). These airborne particles degrade visibility by scattering and absorbing light. Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities.

Modelling undertaken for this ECA proposal shows that at current performance ship emissions in 2020 would negatively impact visibility by contributing to urban haze in U.S. cities which are located near major deep sea ports and also to regional haze in national parks and wilderness areas throughout the U.S. The U.S. government places special emphasis on protecting visibility in national parks and wilderness areas. Section 169 of the Clean Air Act requires the U.S. government to address existing visibility impairment and future visibility impairment in the 156 national parks exceeding 6,000 acres, and wilderness areas exceeding 5,000 acres, which are categorized as mandatory class I federal areas.

At current emissions performance, by 2020, ships would contribute to degraded visibility deciview levels in all monitored class I federal areas. U.S. modelling, conducted in support of this proposal indicates that in southern California's Agua Tibia Wilderness Area, 12.5 percent of visibility impairment would be due to ships while in southern Florida's Everglades National Park, 6 percent of poor visibility would be attributable to ships. Even inland class I federal areas ships are contributing to visibility degradation. In 2020, about 2.5 percent of visibility degradation in the Grand Canyon National Park located in the State of Arizona would be from ships, while almost 6 percent of visibility degradation in the State of Washington's North Cascades National Park would be from ships.

5.4 Ozone Impacts on Forest Health

Air pollution impacts the environment and adversely affects ecological systems, leading to changes in the biological community (both in the diversity of species and the health and vigour of individual species). As an example, many studies have shown that ground-level ozone reduces the health of plants including many commercial and ecologically important forest tree species throughout the United States (Review of the NAAQS for Ozone; U.S. 2007).

When ozone is present in the air, it can enter the leaves of plants, where it can cause significant cellular damage. Since photosynthesis occurs in cells within leaves, the ability of the plant to produce energy by photosynthesis can be compromised if enough damage occurs to these cells. If enough tissue becomes damaged it can reduce carbon fixation and increase plant respiration, leading to reduced growth and/or reproduction in young and mature trees. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stresses (e.g., harsh weather). Because ozone damage can consist of visible injury to leaves, it also reduces the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affects scenic vistas in protected natural areas.

Assessing the impact of ground-level ozone on forests involves understanding the risk/effect of tree species to ozone ambient concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risk/effect of particular plants to ground-level ozone, scientists have developed ozone-exposure/tree-response functions by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." (Chappelka et al, 1998).

With knowledge of the distribution of sensitive species and the level of ozone at particular locations, it is possible to estimate a "biomass loss" for each species across their range. The United States, undertook this analysis for 2020 with and without ship emissions to determine the benefit of lowering these emissions on sensitive tress species in the Eastern half of the U.S. The biomass loss attributable to shipping appears to range from 0-6.5 percent depending on the particular species. The most sensitive species in the U.S. to ozone related biomass loss is black cherry; the area of its range with more than 10 percent biomass loss in 2020 decreased by 8.5 percent when emissions from ships were removed. Likewise, yellow-poplar, eastern white pine, aspen, and ponderosa pine saw areas with more then 2 percent biomass loss reduced by 2.1 percent to 3.8 percent in 2020. This 2 percent level of biomass loss is important, because a consensus workshop on ozone effects reported that a 2 percent annual biomass loss causes harm due to the potential for compounding effects over multiple years as short-term negative effects on seedlings affect long-term forest health (Prasad et al., 2003; Heck et al.,1997).

5.5 Conclusion

In addition to their impacts on human health, emissions for ships also harm many sensitive environmental areas across the U.S. and Canada. At current emissions performance, by 2020, ships would have an even larger impact on terrestrial and aquatic ecosystems, including areas of natural productivity and critical habitats across a large geographic area in both countries. Adopting the proposed ECA for U.S. and Canada will significantly reduce the annual total sulphur and nitrogen deposition occurring in these sensitive ecosystems and will contribute to the recovery of sensitive ecosystems in both U.S. and Canada. Thus, this proposal for an ECA fulfils the ecosystems portion of criterion 3.1.4 of MARPOL Annex VI, Appendix III.

Sections 3, 4 and 5 have described the assessment that was conducted, demonstrating that emissions from ships operating in the proposed ECA are contributing to adverse impacts on human health and the environment. Throughout these sections, the sources of relevant data and methodologies used have been identified. Where the reader seeks additional details beyond what is described here, the Information Document is available for reference. Thus, each portion of criterion 3.1.4 has been fulfilled.

6 Role of Meteorological Conditions in Influencing Air Pollution

Criterion 3.1.5 *The proposal shall include relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts.*

As reflected in the air quality modelling described in sections 3 and 5, meteorological conditions in the U.S. and Canada ensure that a significant portion of at-sea emissions, for ships travelling as far as 200 nautical miles from shore, are transported to land, where they contribute to harmful human health and ecological impacts. This section outlines the role of meteorology in influencing how emissions of pollutants from ships affect ambient air concentrations over the U.S. and Canada. All of the factors described below were thoroughly taken into account in the ambient air quality modelling.

Once air pollutants have been emitted into the atmosphere, the processes that determine pollutant concentrations in space and time (i.e., advection, diffusion/dilution, deposition, and chemical transformation) are largely determined by meteorology. Day-to-day and hourly variations in air pollutant concentrations are often dependent upon weather features that range in size from the synoptic scale (1000 km) to the local scale (1-100 km). The relative importance of the different meteorological scales depends upon the pollutant's atmospheric lifetime. Pollutants that are highly reactive (e.g., nitric oxide, some volatile organic compounds) will not travel far and thus it is only necessary to consider local scale phenomena in determining their fate. Other pollutants (e.g., black carbon, ozone, sulphur dioxide, and particulate sulphates and nitrates) have been demonstrated to persist for longer times (5-10 days) before being significantly dispersed, deposited, or converted to other species (Clarke et al., 2001; Karamchandani et al., 2006). As a result, while meteorological phenomena of all sizes affect the eventual impacts of ship emissions, the longer range regional transport of pollutants from shipping is largely dictated by large scale meteorological patterns.

The following three specific meteorological phenomena have an important role in the eventual fate of emissions from ships. The first is the direction of the prevailing winds. While there can be exceptions on individual days and at individual locations, typically the mid-latitude regions of the northern hemisphere experience air masses that travel from west to east (Wallace and Hobbs, 2006). As a result, coastal locations along the west coast of the U.S. and Canada frequently experience "onshore" winds that transport marine air over land at multiple levels. Table 6-1 shows how often the air over several large cities originates offshore during the previous 24 hours[P]. Along the Pacific Ocean and the Gulf of Mexico coasts, it is very common to experience air masses that were over water the day before; and, while it is less common, this occurs also along the Atlantic coast.

Table 6-1: Percent of time air masses travelled over marine waters before reaching coastal populations

HIGHLY POPULATED COASTAL LOCATION	SECTOR FROM WHICH TRAJECTORIES ARE CONSIDERED "ONSHORE" (DEG)	FREQUENCY OF "ONSHORE" WINDS DURING 1995-2006 (%)
Prince Rupert	150-300	72
Vancouver	150-300	78
San Francisco	180-330	46
Los Angeles	150-300	46
San Diego	180-330	67
Houston	90-210	59
New Orleans	90-240	49
Miami	30-180	66
New York City	30-180	19
Boston	30-120	13
Halifax	30-210	35
St. John's	0-210	41

Second, the stability of the atmosphere into which emissions are injected can determine how much vertical dilution can occur along the transport path. In certain locations and at certain times of the year, the marine environment is characterized by a shallow temperature inversion (250-500m above ground level (AGL)) caused by the interaction of subsiding (warming and sinking) air and cooler water (Winant et al., 1988). When ship emissions are injected into this shallow boundary layer, concentrated plumes can be maintained for long distances. The meteorological modelling (Grell, et al., 1994; Cote et al, 1998), conducted for the air quality modelling, successfully simulated these phenomena over the Eastern Pacific Ocean and the Northwest Atlantic Ocean. As shown in Figure 6-1, the modelling yielded monthly average mixing heights over these regions that were typically less than 300 m in the summer. This marine inversion prevents the ship emission plumes from being diluted vertically until they make landfall.

[P] Based on 24-hour back trajectories from the HYSPLIT and CMC models (Draxler and Hess, 1997; Page and D'Amours, 1994).

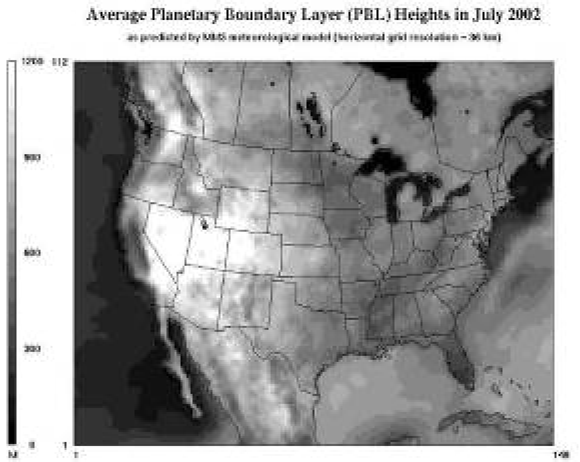


Figure 6-1: Average Modelled Boundary Layer Heights (m AGL) for July 2002

The third important meteorological phenomenon that governs the ultimate fate of pollutants emitted from ocean-going vessels is precipitation. Precipitation determines the amount and extent of wet deposition of pollutants into ecosystems. Wet deposition occurs when gases or particles are 'washed' out of the air by rain, snow, fog, or some other form of precipitation. The amount of precipitation over the water bodies surrounding North America varies by location and season depending upon the synoptic meteorological patterns. High pressure systems (anticyclones) are a common weather pattern over the North American oceans, especially in late spring and early summer. These events are characterised by large areas of subsiding air, light winds, and generally limited precipitation. Figure 6-2 shows the most common synoptic patterns over North America in the summer[Q]. As can be seen, anticyclones of varying strengths are the most prevalent synoptic pattern over the eastern Pacific and southwestern Atlantic Oceans during this time period. These conditions inhibit the removal of pollutants from the atmosphere via deposition until they reach shore. Appendix 3A of the Information Document contains more detail about common synoptic meteorological patterns and key local scale flows. A large fraction of emissions from ocean-going vessels are transported on-shore, prior to removal by dilution, deposition, or chemical transformation.

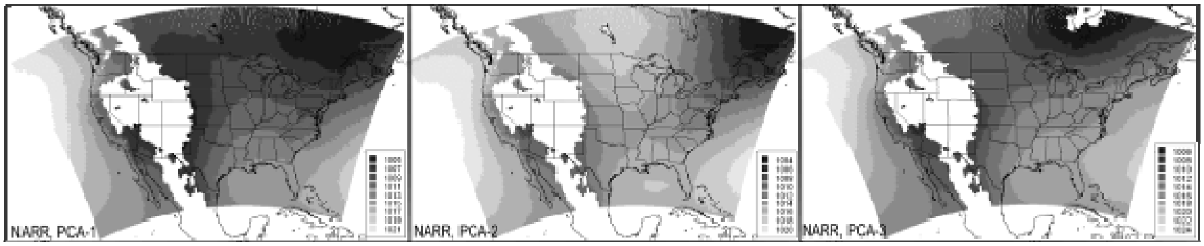


Figure 6-2: Three Most Common Sea Level Pressure Patterns During the Summer in North America

The air quality modelling analyses and the meteorological discussion above focused on southern Canada and the 48-state contiguous portion of the United States, but the same meteorological conditions that result in potential impacts of ship emissions on air pollution over land in that region (e.g., prevailing winds, atmospheric stability, and precipitation patterns) can also result in potential impacts over Alaska and Hawaii. In fact, the oceanic influence is likely greater over the

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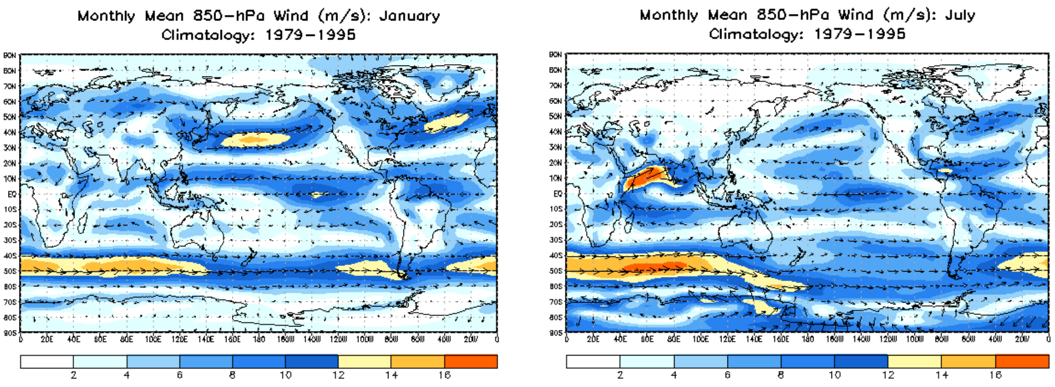
[Q] Derived from a principal component analysis (PCA) of the North American Regional Reanalysis (NARR) dataset (Mesinger, 2006).

Hawaiian Islands and the coastal environs of Alaska (typically more populated than the interior portions of that State).

Because of its great expanse, the climatology of Alaska can differ widely depending upon latitude, altitude, and proximity to the ocean. Generally, the state's meteorology is classified in three zones: maritime, continental, and arctic. The weather in the maritime locations is strongly influenced by the relatively steady-state Pacific Ocean and as a result there are relatively small variations in prevailing winds, humidity levels and temperatures by season and location.[R] Without the stabilizing influence of the ocean waters, the continental and arctic regions can experience large seasonal extremes in temperature, humidity, precipitation, and wind direction. The local meteorology in these two zones is driven by the topography of the surrounding areas, the altitude, and the fraction of sea ice in the Arctic Ocean.

The proximity of the maritime regions to the shipping lanes lead to the conclusion that populations in these areas would be most likely to be adversely impacted by air pollution originating from ships. While wind directions at measuring sites in Alaska can be strongly influenced by topography, the winds typically have an easterly component in populated locations like Anchorage, Juneau, Sitka, and Kenai[S]. Figure 6-3 shows the average prevailing wind direction at 850 hectopascals (hPa) (approximately 1,500 m above ground level) for the months of January and July, averaged over a recent 17 year period. The steering winds at this level indicate the potential for the transport of shipping emissions in the North Pacific (shipping routes from Asia to North America). These winds are driven by common synoptic features that govern weather in this region, specifically the Aleutian low pressure cyclone in the winter and a northeastern Pacific anticyclone in the summer.


Monthly Mean 850–hPa Wind (m/s): January
Climatology: 1979–1995

Monthly Mean 850–hPa Wind (m/s): July
Climatology: 1979–1995

Figure 6-3. Monthly Mean Winds at Approximately the 1,500 Meter Level in January (left) and July (right) Averaged Over the Period from 1979 to 1995. Figures from NOAA Climate Prediction Center.

Not surprisingly, Hawaiian meteorology is also subject to strong maritime influences. Kodama and Businger (1998) summarized the basic meteorology that occurs over this region. Global circulations such as the Hadley cell establish east-northeasterly trade winds as the predominant flow pattern in Hawaii, especially in the warm season. These trade winds can comprise 50-90 percent of the hourly wind directions over the region. Typically, the average height of the surface layer ranges from 1500-3000 m AGL in all seasons in Hawaii. Any emissions input to this layer will remain in this layer unless ventilated by convection or removed by deposition. Ultimately,

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[R] Alaska Climate Research Center, 2009. Alaska Climatology,http://climate.gi.alaska.edu/Climate/index.html.

[S] Western Regional Climate Center, Alaska prevailing wind directions, http://www.wrcc.dri.edu/htmlfiles/westwinddir.html.

as there are shipping lanes on all sides of the main Hawaiian Islands; regardless of which way the wind blows, there is a high potential for ship emissions to affect air pollution over land.

In conclusion, meteorological conditions in the U.S. and Canada ensure that a significant portion of at-sea emissions are transported to land, where they contribute to harmful human health and ecological impacts. These conditions are incorporated into the air quality modelling described earlier in this document. Thus, this proposal for an ECA fulfils criterion 3.1.5 of MARPOL Annex VI, Appendix III.

7 Shipping Traffic in the Proposed Area

Criterion 3.1.6 *The proposal shall include the nature of the ship traffic in the proposed Emission Control Area, including the patterns and density of such traffic.*

7.1 Shipping Traffic Patterns

Together, the United States and Canada account for more than 20 percent of goods shipped via ocean going vessels (U.S. Dept of Transportation, 2008). The U.S. typically sees over 64,000 vessel calls (>10,000 DWT) at its ports annually (U.S. Dept of Transportation, 2008), and Canada's ports can see up to 29,000 vessel calls (> 400 GRT). Much of the ship traffic around the U.S. and Canada is upwind of, and in close proximity to, heavily populated areas collectively containing hundreds of millions of inhabitants. In some areas, ships travelling to or from the U.S. and Canada use common lanes, following jointly established protocols. The ship emissions inventories described in section 3.1, and the subsequent analyses of air quality, health and ecosystem impacts, were based on empirical ship traffic and routing.

In order to understand the shipping traffic occurring around the U.S., the U.S. government first evaluated vessel activity. The International Comprehensive Ocean-Atmosphere data set (ICOADS) is the world's largest data set for global marine surface observations, while the Automated Mutual-assistance Vessel Rescue System data set (AMVER) is a voluntary global ship reporting system. Individual ship positions from a merged ICOADS & AMVER data set are shown below (Figure 7.1-1; Wang et al., 2007). From this image, traffic is seen to be present on all U.S. coasts.

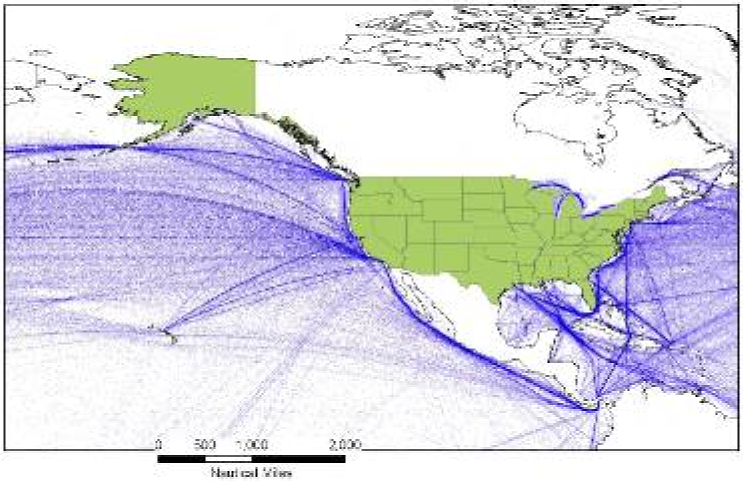


Figure 7.1-1 ICOADS and AMVER Ship Position Data for 2000-2002

Based on this ship position data, the Ship Traffic, Energy, and Environment Model (STEEM) was used to estimate ship pattern, density, activity and emissions. STEEM uses data from ICOADS, AMVER, U.S. Army Corps of Engineers Foreign Traffic Entrances & Clearances data set, and Lloyd's Shipping Information Database as input. STEEM assumes that the spatial distribution of ship reporting frequencies represents the distribution of ship traffic intensity, and that emissions are proportional to intensity of activity. The model then creates shipping lanes, which are a statistical representation of the pathways commonly used by ships (Wang et al., 2007). All ships are located on a lane, and each lane's width is a product of ship traffic intensity and navigational constraints. Using this data, STEEM produces emission estimates.

Traffic density and patterns can be observed from STEEM output. A higher level of emissions indicates higher anticipated ship traffic in an area. CO_2 emissions, which are directly proportional to engine power and fuel consumption, are shown below (Figure 7.1-2). CO_2 emissions produced by STEEM demonstrate the statistically most likely paths for ships to take as they travel between ports. A relatively higher level of CO_2 emissions in an area indicates relatively higher levels of traffic.

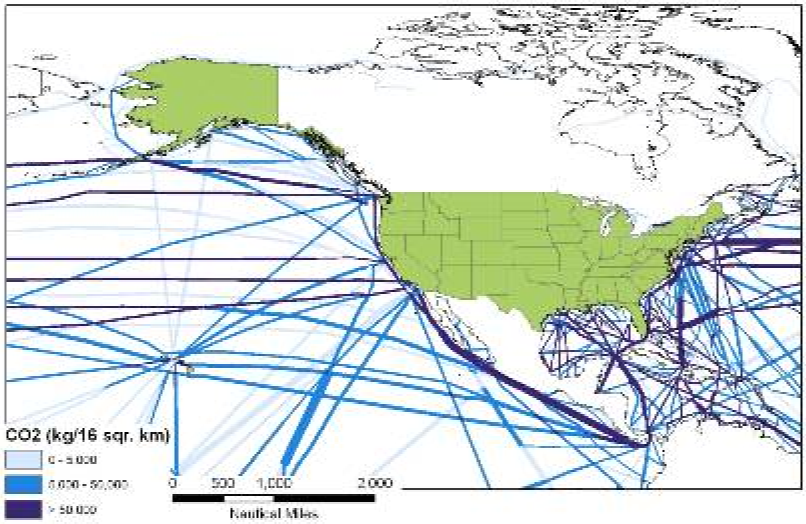
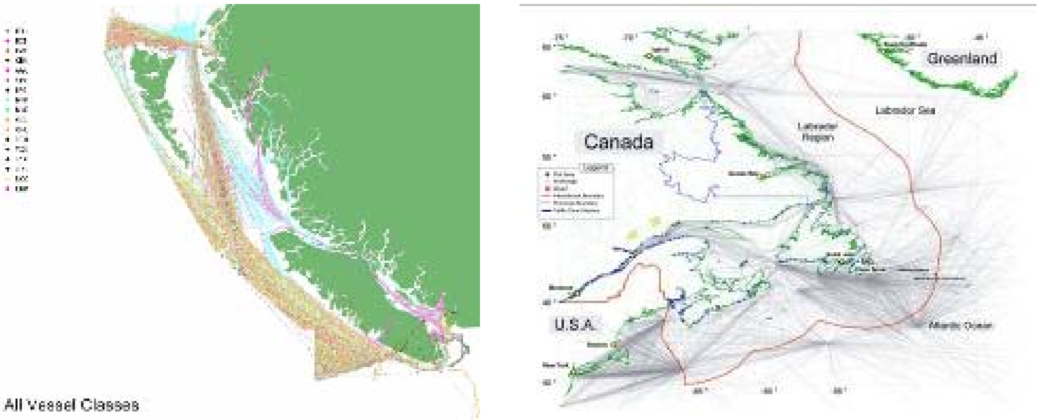


Figure 7.1-2 STEEM Model Representation of Shipping Traffic Patterns and Density

Environment Canada also used the STEEM Network in conjunction with detailed ship traffic data from the Canadian Coast Guard (CCG). While ships over 500 gross tonnes and/or involved with the transport of dangerous goods are sailing in Canadian waters, they are required to report their movements to CCG. Using this data, with STEEM, a detailed picture of vessel traffic in Canadian waters was determined.

For Canada's Pacific coast, the ship emissions inventory relied on vessel traffic control data (ship position and speed) for each ship calling Canada during the 12-month emissions inventory period. High-resolution modelling of ambient air quality modelled emissions from individual ships during air quality episodes. Figures 7.1-3 show 2005/6 vessel traffic data for the Pacific coast of Canada, one of the busiest shipping areas of Canada, along with the approximate ship trajectories on the Atlantic coast of Canada in 2007. This area includes several offshore terminals. The Port of Saint John, New Brunswick alone saw 1,272 merchant vessels and tankers in 2007. Shipping trajectories are also seen off the coast of Labrador. The ships seen here mostly consist of vessels transiting through Canadian waters to Denmark or continuing to Canada's Arctic.



Figures 7.1-3 (Left) International Ship Traffic Calling Canada's Pacific Coast in 2005/6 (Chamber of Shipping of British Columbia, 2007). Different Colours Represent Different Vessel Classes. (Right) Ship Traffic Calling Canada's Atlantic Coast in 2007 (SENES Consultants Ltd., 2008)

7.2 Conclusion

The nature, patterns, and density of the shipping traffic in the proposed ECA have been described. In addition, these shipping patterns provide the foundation for the emissions inventory and air quality modelling described in Section 3. Thus, this proposal for an ECA fulfils criterion 3.1.6 of MARPOL Annex VI, Appendix III.

8 Control of Land-based Sources

Criterion 3.1.7 *The proposal shall include a description of the control measures taken by the proposing Party or Parties addressing land-based sources of SO_X, NO_X and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI.*

8.1 Land-based Emissions Controls of NO_X, SO_X and PM in the U.S. and Canada

Governments in the U.S. and Canada have already imposed restrictions on emissions of NO_X, SO_X, PM and other air pollutants, from a wide range of land-based industrial (stationary) and transportation (mobile) sources as well as consumer and commercial products. For the period from 1990 to 2007, total emissions of NO_X, SO_X and PM[T] from all reported sources in the United States and Canada were reduced 30 percent, 43 percent and 26 percent respectively, even while U.S. and Canadian combined gross domestic product rose 67 percent (inflation-adjusted) (U.S. EPA, 2007; Environment Canada, 2006). The most significant sources have applied advanced emission control technology where feasible, reducing emissions by as much as 99 percent in many cases. Further reductions are expected as older facilities and vehicles are replaced by newer sources subject to even stricter requirements.

The U.S. and Canadian Governments have applied a wide range of programmatic approaches to achieve the significant reductions in air pollution described above. Regulatory regimes typically

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[T] For these reported sources, the particulate matter emissions inventory was tracked in terms of PM_{10} (particles with aerodynamic diameter less than 10 μm) rather than $PM_{2.5}$ because many sources emit a large fraction of coarse PM.

either mandate or provide incentives for emissions after-treatment, cleaner fuels or raw materials, improved practices, as well as new processes or technologies.

Significant emission reductions of NO_X and SO_X in the U.S. have been achieved via performance standards for new combustion sources and market-based programs that cap emissions at the regional level. Since 1996, the Acid Rain Program and NO_X Budget Trading Program have been highly successful at drastically reducing both NO_X and SO_X from power plants in the Eastern U.S. Since 2004, NO_X, SO_X and PM emissions from highway and non-road heavy duty trucks and equipment in both the U.S. and Canada have been decreasing with performance and emission standards that will be completely phased in by 2010. To allow technology to advance, diesel fuel for use in vehicles in the U.S. and Canada has been reduced to less than 0.0015 percent (15 parts per million by weight) sulphur, and diesel fuel for use in off-road equipment, locomotives and domestic marine vessels will be reduced to this level by 2012.

Although the constitutional and legal frameworks in Canada are different, the Government of Canada's policy is to align emissions requirements for vehicles, engines and fuels with the requirements of the United States. The proposed ECA designation will maintain this policy. The governments of Canada's provinces impose strict regulatory and/or permitting regimes on emissions from industrial and commercial sources. Generally these regimes require "best available" emissions performance. In addition, Canada is considering strict new emissions requirements for the following sectors: electricity generation produced by combustion; oil and gas (including upstream oil and gas, downstream petroleum, oil sands, and natural gas pipelines); forest products (including pulp and paper and wood products); smelting and refining (including aluminium, alumina, and base metal smelting); iron and steel; iron ore pelletizing; potash; cement; lime; and chemicals production, including fertilizers.

As land-based sources of emissions are increasingly controlled, the contribution of ship emissions to public health and environmental impacts would increase without action to reduce ship emissions.

8.2 Conclusion

As described above, extensive control measures have been adopted in the U.S. and Canada, to reduce air pollution from land-based sources. Thus, this proposal for an ECA fulfils criterion 3.1.7 of MARPOL Annex VI, Appendix III.

9 Relative Costs of Reducing Emissions from Ships

Criterion 3.1.8 *The proposal shall include the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.*

The costs of the proposed ECA are expected to be small compared to the improvements in air quality and compare favourably to the costs of land-based emission controls. In addition, they are expected to have a modest economic impact. This section describes our estimates of low sulphur fuel production costs and vessel hardware and operating costs. These costs are then compared to those associated with land-based controls. In addition, this section discusses the anticipated economic impact of the proposed ECA.

The costs presented here are based on the application of ECA controls and compliance with ECA standards in 2020. To be consistent with the emissions inventory (Section 3) and the resulting benefits (Sections 4 and 5), the estimated costs are presented for the year 2020 only. This means that fuel production costs and other vessel operating costs (e.g. the use of urea on an SCR-equipped vessel) are included as relevant to all vessels expected to visit the ECA in 2020, however hardware costs are only included as relevant to new vessels expected to be constructed during 2020 (and expected to visit the ECA). A separate discussion is included that presents the estimated one-time hardware costs that may be incurred by some vessels to accommodate the use of low sulphur fuel; however, these costs are expected to be incurred prior to 2015 and are not included in the 2020 total.

9.1 Summary of the Total Costs in 2020

The total estimated cost in 2020 of improving ship emissions from current performance to ECA standards includes both hardware and operational costs. The hardware costs include the component and assembly costs of Selective Catalytic Reduction (SCR) NO_X emission control systems installed on ships visiting the proposed ECA and built in 2020. The hardware costs presented here also include additional equipment (e.g. tanks, piping) that may be installed on some vessels, built in 2020, to accommodate the use of low sulphur fuel in 2020. The operational costs include the differential cost of using low sulphur fuel incurred by all vessels visiting the proposed ECA, and the use of urea on vessels that are equipped with urea based SCR systems to meet Tier III NO_X standards. The total cost in 2020 including both hardware and operational costs is expected to be \$3.2 billion,[U] two-thirds of which is expected to be operational costs. Table 9.1-1 summarizes these costs.

Table 9.1-1 2020 Total Incremental Cost of the Proposed ECA

TYPE OF COST	COMPLIANCE STRATEGY	COST IN 2020 (BILLIONS USD)
Operating Costs (apply to all ships)	Fuel Switching	\$1.9
	Urea Consumption (for SCR-equipped engines)	\$0.17
Hardware Costs (apply to ships built in 2020)	Fuel Switching	\$0.03
	SCR	\$1.1
Total Costs		**\$3.2**

9.2 Fuel Production Costs

This section presents estimates of the cost associated with producing compliant fuel. Distillate fuel will likely be needed to meet the 0.1 percent fuel sulphur limit, beginning in 2015, for operation in ECAs.[V] As such, the primary cost of the fuel sulphur limit will be that associated with switching from heavy fuel oil to higher-cost distillate fuel, when operating in the ECA. Some engines already operate on distillate fuel and would not be affected by fuel switching costs. Distillate fuel costs may also be affected by the need to further refine the distillate fuel to meet the 0.1 percent sulphur limit. To investigate these effects, studies were performed on the impact of a U.S./Canada ECA on global fuel production and costs. These studies, which are summarized below, include economic modelling to project bunker fuel demand and refinery modelling to assess the impact of a U.S./Canada ECA on fuel costs.

[U] Cost estimates presented in this section are in 2006 U.S. dollars.

[V] As an alternative, an exhaust gas cleaning device (scrubber) may be used. This analysis does not include the effect on distillate fuel demand of this alternative approach. It is expected that scrubbers would only be used in the case where the operator determines that the use of a scrubber would result in a cost savings relative to using distillate fuel. Therefore we are only estimating the cost of compliance using distillate fuel here as we believe this is the most likely approach.

To assess the effect of an ECA on the refining industry, an understanding and characterization of the fuels market was required. Research Triangle Institute (RTI) was contracted to conduct a fuels study using an activity-based economic approach (RTI, 2008). The study established baseline bunker fuel demand, projected a growth rate for bunker fuel demand, and established future bunker fuel demand volumes. These volumes then became the input to the World Oil Refining Logistics and Demand (WORLD) model to evaluate the effect of an ECA on fuel cost.

The WORLD model was run by Ensys Energy & Systems, the owner and developer of the refinery model. The WORLD model is the only such model currently developed for this purpose, and was developed by a team of international petroleum consultants. It has been widely used by industries, government agencies, and OPEC over the past 13 years, including the Cross Government/Industry Scientific Group of Experts, established to evaluate the effects of the different fuel options proposed under the revision of MARPOL Annex VI. The model incorporates crude sources, global regions, refinery operations, and world economics. The results of the WORLD model have been comparable to other independent predictions of global fuel, air pollutant emissions and economic predictions.

To determine the impact of the U.S./Canada ECA, the WORLD model was employed using the same basic approach as for the IMO expert group study (Ensys, 2009). Modelling was performed for 2020 in which the control case included a fuel sulphur level of 0.1 percent in an area extending 200 nm from the U.S. and Canadian coasts. The baseline case was modelled as “business as usual” in which ships continue to use the same fuel as today. Since the initial model runs, oil prices have both increased and fluctuated greatly. In response to this real-world effect, additional runs were performed using new reference case and high oil price estimates that were recently released by the U.S. Energy Information Administration. In addition to increased oil price estimates, the updated model accounts for increases in natural gas costs, capital costs for refinery upgrades, and product distribution costs.

Consistent with the analyses conducted by the Cross Government/Industry Scientific Group of Experts in support of the recent revisions to Annex VI to MARPOL, it is expected the appropriate fuels will be available in sufficient quantities to meet the agreed-to ECA emission limit implementation dates.

Because only a small portion of global marine fuel will be consumed in the ECA, the overall impact on global fuel production will be small. Global fuel use in 2020 by ships is projected to be 500 million tonnes/yr. Of this amount, 90 million tonnes of fuel will be used for U.S./Canadian trade, or about 18 percent of total global fuel use. In the proposed ECA, less than 16 million tonnes of fuel will be consumed in 2020, which is about three percent of total global marine fuel use.

There are two main components to projected increased marine fuel cost associated with the ECA. The first component results from shifting from operation on residual fuel to operation on higher cost distillate fuel. This is the dominant cost component. There is also a small cost associated with desulphurizing the distillate to meet the 0.1 percent sulphur standard in the ECA. Based on the WORLD modelling, the average increase in costs associated with switching from marine residual to distillate will be $145 per tonne.[W] This is the cost increase that will be borne by

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[W] Note that distillate fuel has a higher energy content, on a per tonne basis, than residual fuel. As such, there is an offsetting cost savings, on a per tonne basis, for switching to distillate fuel. Based on a 5 percent higher energy content for distillate, the net equivalent cost increase is estimated as $123 for each tonne of residual fuel that is being replaced by distillate fuel.

the shipping companies purchasing the fuel. Of this amount, $6 per tonne is the increase in costs associated with distillate desulphurization.

9.3 Vessel Costs

9.3.1 Technology Overview

There are a number of different technologies and combinations of technologies available to meet ECA NO_X and low sulphur fuel standards. Tier III NO_X standards will apply to new ships built as of 2016, and will most likely be met through the use of aftertreatment such as SCR. SCR reduces NO_X to elemental nitrogen (N_2) and water by using small amounts of a reducing agent, such as ammonia (NH_3). Other technologies to reduce NO_X include water systems such as fumigation, emulsion, and direct water injection, which work by using water in the combustion chamber to absorb the heat of combustion and lower the peak combustion temperature. Another strategy to reduce NO_X is to use exhaust gas recirculation (EGR) which also works by lowering combustion temperatures in addition to reducing the amount of available oxygen. The cost analysis presented here was based on the use of urea-based SCR to meet the Tier III NO_X standards which we consider to be the most likely approach.

The 2015 fuel sulphur standards will apply to all ships operating in an ECA as of 2015. While the fuel sulphur standards can be met through the use of low sulphur fuel, alternative compliance strategies may be allowed, such as sea water scrubbers, as long as the alternative strategy provides the same SO_X reductions as using low sulphur fuel. We consider the use of low sulphur fuel to be the most likely approach, therefore this cost analysis was based on the use of switching to low sulphur fuel as the method of control of reduce PM/SO_X emissions when operating in the proposed ECA. Section 9.2 presents the incremental costs associated with the production of low sulphur fuel while Section 9.3.4.2 presents the incremental costs associated with the consumption of this fuel by vessels visiting the proposed ECA.

9.3.2 Methodology

To estimate the hardware costs associated with ships visiting the proposed ECA, we needed to first characterize the fleet of ships that may be expected to operate in the ECA in 2020. In order to be consistent with the emissions inventory presented in Section 3, a future fleet was developed using the same 2002 baseline fleet data and regionally derived growth rates used in the inventory. The growth rates were applied to the 2002 fleet to estimate the size and makeup of a future fleet in 2020. Average characteristics by ship type and engine type were also developed from the 2002 baseline fleet data, and were used to characterize the 2020 fleet.

To determine the cost impacts the proposed ECA will have on vessels that visit it, ICF International, (ICF, 2009) was contracted by the U.S. EPA to conduct a cost study of various compliance strategies expected to be used to meet the new NO_X standards and fuel sulphur requirements. Cost estimates were developed for the applications of these technologies over a range of engine types and sizes. These estimates were then used to develop a dollar-per-kilowatt ($/kW) value that could be scaled according to engine type and power. The $/kW value was applied to the total average propulsion power determined for each ship type to estimate a per-vessel cost. The per-vessel hardware costs were then applied to the number of applicable new vessels in 2020 to determine the total cost in 2020.

9.3.3 Hardware Costs

9.3.3.1 SCR Hardware Costs

Input from a number of manufacturers was incorporated into the ICF study to estimate the fixed and variable costs of applying SCR on a range of ‘typical’ engine sizes (see Table 9.3-4) and engine characteristics (e.g. stroke, number of cylinders, speed, etc.). The costs for these typical engine sizes and types were then used to derive a $/kW hardware cost for SCR (see Table 9.3-1 below). The $/kW values were then applied to the propulsion power of each ship in the projected 2020 fleet to determine the SCR hardware costs for the ECA in 2020. The estimated total hardware cost for vessels built in 2020, visiting the ECA using SCR as a NO_X control strategy to meet Tier III, is $1.1 billion.

Table 9.3-1 Estimated Selective Catalytic Reduction Hardware Costs ($/kW)

TECHNOLOGY		ENGINE SPEED	ENGINE SIZE RANGE (KW)	$/KW
NO_X Reductions	SCR	Medium	4,500 – 18,000	$41- $83
		Slow	8,500 - 48,000	$46 -$76

9.3.3.2 Fuel Switching Hardware Costs

While most vessels currently carry some distillate fuel even if their main engines operate on heavy fuel oil, some ships may need to add additional distillate capacity to call on the proposed ECA. To estimate the potential cost of using fuel-switching as a compliance strategy for vessels expected to visit the ECA, ICF estimated the costs of adding additional capacity separately for new and existing vessels. A $/kW value, see Table 9.3-2, was determined to estimate the per-vessel cost; however, the number of vessels that may require such a modification was not readily available.

To estimate the number of vessels that may require additional hardware to accommodate the use of low sulphur fuel, we used Lloyd’s Sea-web (Lloyd’s, 2008) database to determine the distillate carrying capacity of the current global fleet. The entire global fleet listed in Lloyd’s database in 2008, consisting of over 43,000 vessels was analyzed to determine the current distillate fuel capacity. For the nearly 20,000 vessels that had provided Lloyd’s with actual fuel tankage information, cruise speed, and propulsion engine power data, we were able to individually estimate how far each vessel could travel on its existing distillate carrying capacity. In order to analyze the capability of the current fleet to call on the proposed ECA, we determined how many of these vessels could travel the distance between the port of Los Angeles and the port of Tacoma, which is approximately 1,140 nm (see Table 9.3-2 below). The distance between the port of Los Angeles and the port of Tacoma is one of the longest trips within the proposed ECA a ship would likely travel without stopping at another port. Using a distance of 1,140 nm to evaluate whether or not a vessel would require a retrofit should overestimate the actual number of vessels that will require such a modification.

The percentage of existing vessels, by vessel type, determined to require a retrofit (shown in Table 9.3-3) was assumed indicative of the percentage of new vessels built in 2020 that may require extra hardware to accommodate the use of low sulphur fuel. We then estimated the cost of adding this additional equipment to those new vessels. Table 9.3-2 presents the $/kW cost associated with this extra hardware on new vessels. The costs associated with installing additional fuel capacity on new vessels built in 2020 that may visit the ECA are estimated to be $30 million.

Table 9.3-2 Fuel Switching Hardware Costs

TECHNOLOGY		ENGINE SPEED	ENGINE SIZE RANGE (KW)	$/KW
SO_X/PM Reductions	Fuel Switching Hardware Costs – *New Vessels*	Medium	4,500 – 18,000	$3.34 - $8.00
		Slow	8,500 - 48,000	$1.65 - $5.24
	Fuel Switching Hardware Costs – *Existing Vessels*	Medium	4,500 – 18,000	$4.56 - $10.45
		Slow	8,500 - 48,000	$2.25 - $6.97

Table 9.3-3 Ships that Can Travel 1,140 nm on Existing Distillate (LFO) Carrying Capacity

Ship Type	Total # Ships	Total # Ships That Only Carry LFO	Total # Ships That Carry LFO + Another Fuel	Ships that Carry LFO + Another Fuel that May Need a Modification		Total # Ships that Carry No LFO	% LFO	Total of ALL Ships that May Need a Modification	
				#	%			#	%
General Cargo	4600	1900	2300	200	9%	370	8%	580	13%
Tanker	5900	740	4900	1600	33%	280	5%	1900	33%
Container	1900	45	1700	910	53%	140	7%	1000	55%
Bulk Cargo	3600	230	3000	1600	53%	400	11%	2000	55%
RoRo	510	70	380	30	8%	60	12%	90	18%
Auto Carrier	360	20	310	20	7%	40	10%	60	16%
Misc.	1600	1100	210	70	34%	210	14%	280	18%
Passenger	710	170	460	270	59%	85	12%	360	51%
Reefer	530	60	440	20	4%	25	5%	40	8%

Not included in the 2020 cost totals, but mentioned here for the benefit of ship owners are estimated hardware retrofit costs for existing ships, associated with switching to low sulphur fuel (see Table 9.3-2). These retrofit costs will be incurred by some of the vessels that may call on the ECA in 2015, and are estimated to be $327 million. These costs are expected to be incurred prior to 2015 and are not included in the 2020 cost totals.

9.3.4 Vessel Operating Costs

9.3.4.1 SCR Operating Costs

In addition to the SCR hardware costs in $/kW listed above in Table 9.3-1, ships built as of 2016 would also incur operating costs associated with SCR's use of urea. An estimated price of $1.52 per gallon was established for a 32.5 percent urea solution delivered in bulk to the ship through research completed by ICF combined with historical urea price information. This cost analysis used a urea dosing figure of 7.5 percent of the brake-specific fuel consumption value to estimate how much urea would be used by different engine types and sizes. Table 9.3-4 shows the "Typical Engine Types" provided by ICF and used in our cost analysis and the associated urea cost estimates for those engine types. The cost in 2020 associated with the use of urea by ships built as of 2016 is based on total urea consumption of nearly 100 million gallons. This operational cost is estimated to be approximately $170 million.

Table 9.3-4 Urea Costs per Hour for the "Typical Engine Types" Used in this Analysis

ENGINE SPEED	MEDIUM	MEDIUM	MEDIUM		LOW	LOW	LOW
Engine Power (kW)	4,500	9,500	18,000		8,500	15,000	48,000
Cylinders	9	12	16		6	8	12
Liters/cylinder	35	65	95		380	650	1400
Engine Speed (rpm)	650	550	500		130	110	100
BSFC (g/kWh)	210	210	210		195	195	195
Aqueous Urea Cost per hour	***$19***	***$ 40***	***$ 76***		***$33***	***$59***	***$188***

9.3.4.2 Low Sulphur Fuel Operational Costs

The primary operating costs associated with improving ship emissions from current levels to those meeting ECA emission standards is due to the differential fuel costs for ships. The fuel costs that would be incurred by all vessels in 2020 include the differential cost estimated to be $6/tonne for using 0.1 percent sulphur fuel incurred by ships that were using 0.5 percent sulphur fuel, and $145/tonne for vessels switching from residual fuel to 0.1 percent sulphur fuel.

The incremental consumption of 0.1 percent sulphur distillate fuels by ships operating within the ECA was estimated by the emissions inventory models presented in Section 3; the total estimated additional fuel costs for the proposed ECA are $1.9 billion in 2020.

9.4 Cost to Shipping Industry in Comparison with Land-based Measures

As discussed above in Sections 3, 4, and 5, the proposed ECA is expected to bring a great deal of societal and environmental benefits. Section 9.1, above, summarizes the various costs of the proposed ECA. To evaluate how cost effective the proposed ECA will be, compared to other control programs, at providing the expected emission reductions, the measure of cost-effectiveness, a ratio of engineering costs incurred per tonne of emissions reduced was used.

As is shown in this section, the NO_X, SO_X and PM emissions reductions from the proposed ECA compare favourably—in terms of cost-effectiveness—to other land-based control programs that have been implemented.

9.4.1 ECA Cost-Effectiveness

Section 3.1 of this document summarizes the inventory analyses from which the U.S. and Canadian projections of pollutant reductions are drawn. Reducing ship emissions from today's performance to ECA standards will, in 2020, reduce approximately 294,000 metric tonnes of NO_X, 85,400 tonnes of $PM_{2.5}$ and 834,000 tonnes of SO_X.

As described above, the costs of the proposed ECA in 2020 include costs to refiners to produce additional distillate fuel, as well as costs for engine controls, catalysts and reductants to reduce NO_X emissions and costs for additional tankage[X] for distillate oil. The timing of costs incurred varies, as some costs (i.e. capital expenditures) will be near-term, while others, such as operational costs, are incurred over time in small increments.

[X] Scrubber costs were not included because 100% of ships were assumed to use distillate fuel. It is expected that any use of scrubbers would only decrease total costs compared to 100% use of distillate fuel (otherwise scrubbers would not be used).

According to the methods used in support of regulatory development for other emissions sources in the U.S., the estimated cost-effectiveness of the U.S. portion of the ECA will be $US2,600 per tonne of NO_X removed, $US11,000 per tonne of $PM_{2.5}$ removed, and $US1,200 per tonne of SO_X removed. Half of the costs of fuel switching, including production and tankage, were allocated to PM and half were allocated to SO_X because the costs incurred to reduce SO_X emissions directly reduce emissions of PM as well. Although cost-effectiveness was not calculated for the Canadian portion of the ECA for methodological reasons; it is expected to be similar.

9.4.2 Land-Based Control Program Cost-Effectiveness

The cost of reducing air pollution from land based sources in the U.S. has ranged greatly, depending on the pollutant, the type of control program and the nature of the source. The cost of NO_X reductions has typically ranged from $200 per tonne of NO_X to over $12,000 per tonne. The cost of PM reductions has typically ranged from $2,000 per tonne of PM reduced to over $50,000 per tonne. The cost of SO_X reductions has typically ranged from $200 to $6,000 per tonne.

Programs that are designed to capture the efficiency of designing and building new compliant sources tend to have better cost-effectiveness than programs that principally rely on retrofitting existing sources. Even considering the retrofitting programs, the control measures that have been implemented on land-based sources have been well worthwhile when considering the benefits of the programs.

As an illustration, in 1998, the U.S. Government concluded that NO_X emissions reductions from retrofitting power plants that can be made for less than $3,400 per tonne (in 2008 dollars) are “highly cost-effective,” considering the emissions reduced by the advanced control technology, not including societal benefits. More detailed cost comparisons are presented in Chapter 5 of the Information Document.

9.5 Economic Impacts on Shipping Engaged in International Trade

An Economic Impact Analysis (EIA) provides information about the potential economic consequences of a regulatory action. This analysis is performed using basic microeconomic theory to simulate how producers and consumers of products and services affected by the emission requirements can be expected to respond to an increase in production costs as a result of the new emission control program for ships operating in the proposed ECA.

International shipping is different from other transportation service markets in that, for most goods, there are no reasonable alternative shipping modes. Approximately 90 percent of world trade by tonnage is moved by ship, and ships provide the most efficient method to transport these goods on a tonne-mile basis. As a result, demand for international shipping services is not expected to change as a result of the increase in costs associated with the proposed ECA, and all of these costs are expected to be passed on to consumers of these services through an increase in freight rates. These costs, in turn, are expected to be passed on to the consumers of goods transported.

The costs associated with the proposed ECA are described earlier in this section. We estimate that these costs added to the total cost of shipping goods to or from a U.S. or Canadian origin or destination will result in only a modest increase in the costs of goods transported by ship. We estimate that the cost to comply with the proposed ECA requirements will increase the price of a new vessel by 2 percent or less. With regard to operating costs, analysis of a ship in liner service between Singapore, Seattle, and Los Angeles/Long Beach, which includes about 1,700 nm of operation in the proposed ECA, suggests that improving from current performance to ECA standards would increase the operating costs by about 3 percent. This would increase the price of shipping a container by about $18, also about 3 percent. Similarly, the impacts on cruise vessels are expected to be small. The per passenger price of a seven-day Alaska cruise operating entirely within the ECA would increase about US$7 per day. The expected increase in total operating costs would be smaller for ships that operate on routes with less time spent in the proposed ECA.

9.6 Conclusion

In conclusion, the proposed ECA will be highly effective at achieving emissions reductions of NO_X, SO_X and PM for the given costs. Further, the relative costs of reducing emissions from ships and the economic impacts on the international shipping industry will be reasonable. Thus, this proposal for an ECA fulfils criterion 3.1.8 of Annex VI, Appendix III.