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MODELED ESTIMATES OF HUMAN HEALTH AND ECOLOGICAL IMPACTS FROM THE ESTABLISHMENT OF A NORTH AMERICAN EMISSIONS CONTROL AREA (ECA)

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Abstract: Previous studies have concluded that emissions from ocean-going marine vessels may cause as many as 60,000 deaths annually worldwide. In this study, emissions of NOx, SOx, and PM from shipping emissions are shown to contribute significantly to poor air quality across North America and are increasingly contributing to the amount of sulfur and nitrogen being deposited in the U.S. and Canada. The outputs from a series of regional air quality simulations, using the Community Multiscale Air Quality (CMAQ) modeling system, were paired with several ecosystem models to look at the impacts of potential regulations on ocean-going vessels on human health and welfare. As part of this analysis, several innovative linkages were developed to relate projected changes in air quality to impacts on health and welfare metrics such as human mortality, acidification of aquatic and terrestrial ecosystems, and forest health. This paper will summarize the results of these integrated modeling systems and demonstrate that reductions in ship emissions would produce widespread benefits that outweigh the costs of any potential controls. Additionally, several sensitivity tests were conducted to quantify the air quality and health impacts of ship emissions at various distances from the North American shoreline. Based on this modeling, a joint proposal from the United States, Canada, and France to amend MARPOL Annex VI to designate specific areas of North American coastal waters as an Emission Control Area (ECA) was accepted by the International Maritime Organization (IMO) in March 2010. This ECA is scheduled to begin to reduce emissions as early as July 2010 and is expected to deliver substantial public health benefits to many people living in the U.S., Canada and French territories, as well as to marine and terrestrial ecosystems over the next decade.

Key words*: air quality impacts of shipping, ozone, fine particulates, acid deposition*

BACKGROUND

A natural by-product of a global economy is the need for transportation of commodities from their source of origin to their source of consumption. Steady growth in international shipping over the past half-century has resulted in emissions from this sector increasingly being viewed as a significant contributor to degraded air quality and health worldwide. Recent studies have shown that shipping-related emissions are responsible for as many as 60,000 cases of premature mortality every year (Corbett *et al.*, 2007; Winebrake *et al.*, 2009).

However, emissions from international shipping and the associated air quality problems have traditionally been difficult to regulate due to jurisdictional issues (Shrader, 2008). To address this issue, the International Maritime Organization (IMO), an agency of the United Nations, established Annex VI of the MARPOL convention to assist in the prevention of air pollution from ships. This international convention allows countries to apply for a designation of an Emissions Control Area (ECA) for specific portions of their coastal waters. Ships operating in a designated ECA are required to not to exceed 0.1 percent fuel sulfur by 2015. This requirement is expected to reduce PM and SOx emissions by more than 85 percent. Additionally, beginning in 2016, vessels operating in an ECA will need to meet engine emissions standards that will result in an 80 percent reduction over present-day NOx emissions. In March 2010, the International Maritime Organization (IMO) member states formally agreed to designate a large portions of U.S., Canadian and French waters as an ECA. Based on modeling analyses described further in this paper, the decision was made to extend the North American ECA boundary to 200 nautical miles from the relevant shorelines.

EPA AIR QUALITY MODELING CONFIGURATION

When considering the potential effects of any particular air quality regulation, it is common practice to apply a photochemical air quality modeling system to estimate the change in air quality expected to occur with the emissions reductions proposed as part of the control program. At their core, air quality models are quantitative approximations of the numerous complex physical and chemical interactions in the atmosphere that determine the formation and fate of air pollutants in the atmosphere. The U.S. government has traditionally used air quality modeling results to support policy decisions and as inputs into regulatory impact analyses. As part of this exercise, a fine-resolution, national air quality modeling analysis was performed to estimate the effect in 2020 of the proposed ECA emissions reductions on future 8-hour ozone concentrations, annual fine particulate matter (PM2.5) concentrations, visibility levels, and acid deposition to watersheds and ecosystems across the U.S.

EPA's Community Multi-scale Air Quality (CMAQ) modeling system was used in this analysis (Byun and Schere, 2006). CMAQ is a publicly available, peer reviewed, state-of-the-science model consisting of a number of science attributes that are critical for simulating the oxidant precursors and nonlinear organic and inorganic chemical relationships associated with the formation of ozone as well as sulfate, nitrate, and organic aerosols. The CMAQ modeling analyses were performed for three separate domains, as shown in Figure 1. This modeling used a parent horizontal grid of 36 km with two nested, finer-scale 12 km grids covering the Eastern and Western U.S. The model extends vertically from the surface to 100 millibars using a sigma-pressure coordinate system. Air quality conditions at the outer boundary of the 36 km domain were downscaled from the global GEOS-Chem model and did not change over the simulated scenarios. Meteorological inputs from 2002 were used as determined by separate retrospective MM5 meteorological modeling.

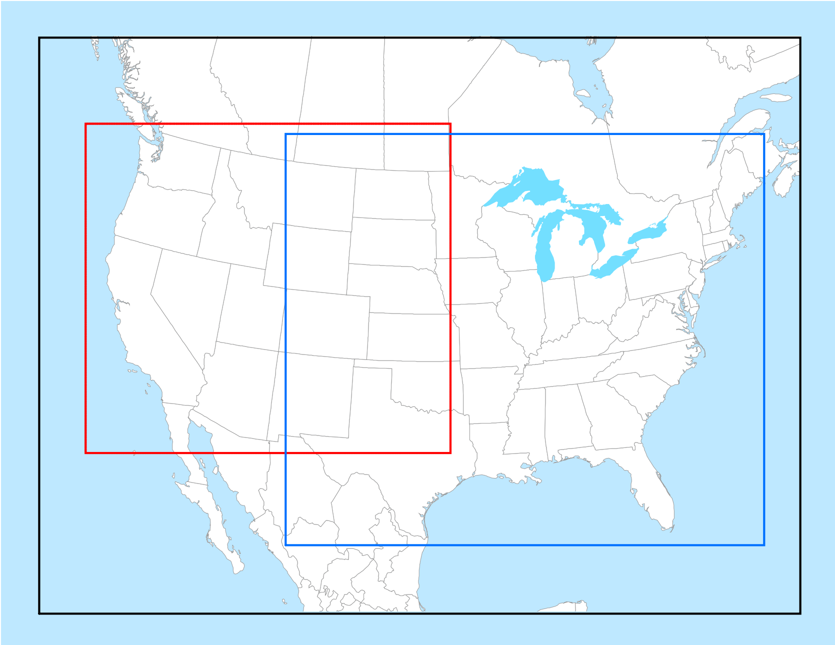

Figure 1. Map of the CMAQ Modeling Domains. The black outer box denotes the 36 km national modeling domain; the red inner box is the 12 km western U.S. fine grid; and the blue inner box is the 12 km eastern U.S. fine grid.

IMPACTS OF ECA ON OZONE AND FINE PARTICULATE LEVELS

High levels of ozone and fine particulates are expected to continue to be a problem over the U.S. for at least the next two decades despite numerous past emission reduction programs. Without further action, emissions from ships will contribute a larger share to the projected levels of ozone and fine particulates as emissions from other sources decrease. The CMAQ modeling shows that the designation of an ECA within 200 nautical miles of the U.S. coastline will have significant benefits to ozone and fine particulates.

Specifically, large improvements in PM2.5 air quality are projected to occur as a result of an ECA designation. The air quality benefit will be largest in coastal areas, exceeding 1.0 ug/m3 annually in some locations. Based on these modeled air quality improvements, the ECA designation is estimated to result in benefits ranging from $27-60 billion dollars due to reduced health costs and reduced premature mortality. Figure 2 shows the improvement in peak 24-hour PM2.5 levels in 2020 as a result of the lower SOx and NOx emissions.

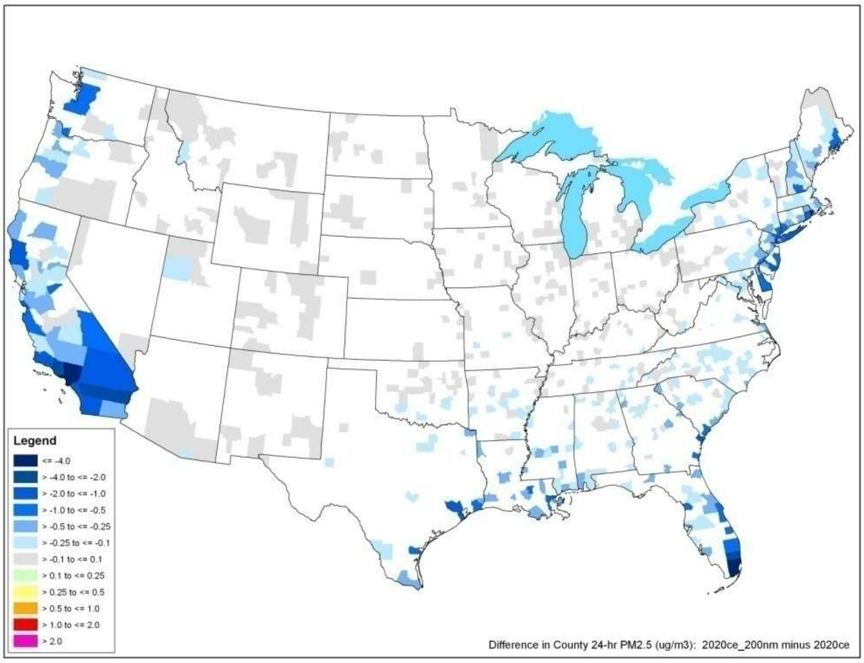

Figure 2. Map of the changes in county-wide 24-hour PM2.5 design values in 2020 after the implementation of a 200 nautical mile ECA over North America. The changes are shown only for those counties with existing fine particulate monitors.

Large improvements in ozone air quality are also projected to occur as a result of an ECA designation. Again, AQ benefits will be greatest in coastal areas. Some locations are projected to experience reductions of 0.5 – 2.0 ppb by 2020 as a result of the tighter ECA NOx engine standards. Figure 3 shows the change in average daily maximum 8-hour ozone levels in 2020 as a result of this reduction in shipping emissions. The modeling shows some areas of ozone increases over portions of Los Angeles and Seattle due to less titration of ozone when NOx shipping emissions are reduced. However, as local emissions of NOx are further reduced in these areas in the future to meet national ambient air quality standards, it is expected that the ozone chemistry will become increasingly favorable to NOx controls.

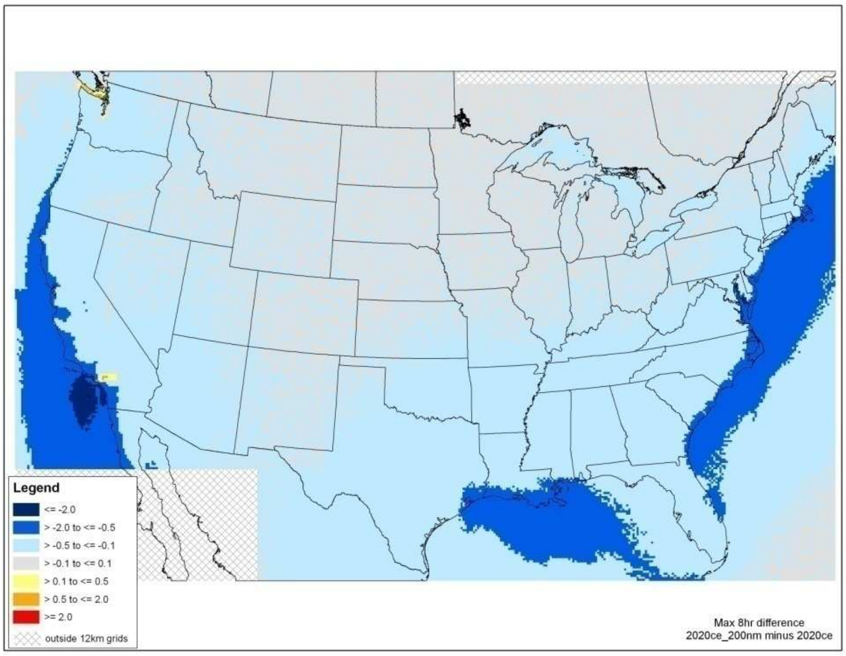

Figure 3. Map of the changes in gridded daily maximum 8-hour ozone values in 2020 after the implementation of a 200 nautical mile ECA over North America.

IMPACTS OF ECA ON ACID DEPOSITION, VISIBILITY, AND ECOSYSTEM HEALTH

Not surprisingly, given the large reductions in NOx and SOx emissions that will occur in the coastal regions over the next decade due to the ECA designation, the modeling also projects large reductions in total nitrogen and total sulfur deposition over the U.S. Reductions of more than ten percent in sulphur deposition are projected in most coastal areas by 2020. Figure 4a and 4b show the change in total nitrogen and sulfur deposition in 2020 based on the absolute outputs of the CMAQ model.

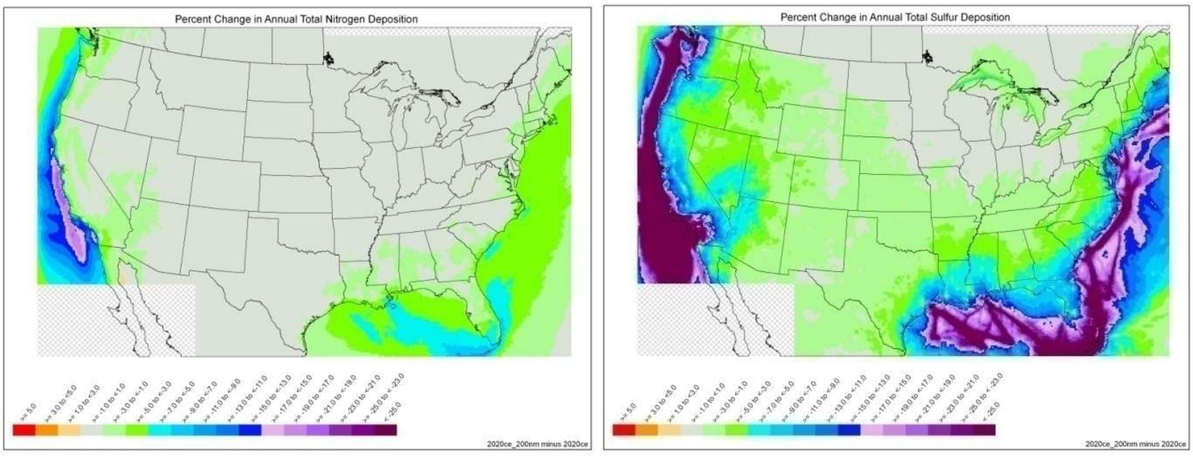

Figure 4. Map of the changes in gridded: a) total nitrogen and b) total sulfur deposition in 2020 after the implementation of a 200 nautical mile ECA over North America.

These reductions in acid deposition lead to a corresponding improvement in ecosystem health. As seen from the preceding results, large ships release emissions over a wide area, and depending on prevailing winds and other meteorological conditions, these emissions may be transported hundreds and even thousands of kilometers across North America. Deposition of nitrogen and sulfur causes acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across the U.S. 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.

As part of the North American ECA application, EPA conducted a case study looking at the Adirondack Mountains of New York and the Blue Ridge Mountains in the State of Virginia. These two areas have long been a focus for environmental issues related to acid deposition. Soils and water bodies, such as lakes and streams, usually buffer the acidity from natural rain with "bases", the opposite of acids from the environment. The poor buffering capability of the soils in both these regions make the lakes and streams particularly susceptible to acidification from anthropogenic nitrogen and sulfur atmospheric deposition resulting from nitrogen and sulfur oxides emissions. Consequently, acidic deposition has affected hundreds of lakes and thousands of miles of headwater streams in both of these regions. The diversity of life in these acidic waters has been reduced as a result of acidic deposition. Sensitivity modeling conducted with CMAQ showed that shipping emissions contributed to several water bodies where greater acid deposition occurred than could be neutralized.

Lastly, among the numerous positive impacts of the ECA designation, the modeling showed that improvements in visibility could be expected in many scenic national parks and monuments across the U.S. Figure 5 shows how visibility will improve across ten Class 1 areas over the U.S. The ECA emissions reductions are projected to result in 2-5 percent improvements in visibility in numerous locations. In some western U.S. locations, the improvements from the ECA program are equivalent to the improvements resulting from all other sector control between 2002 and 2020.

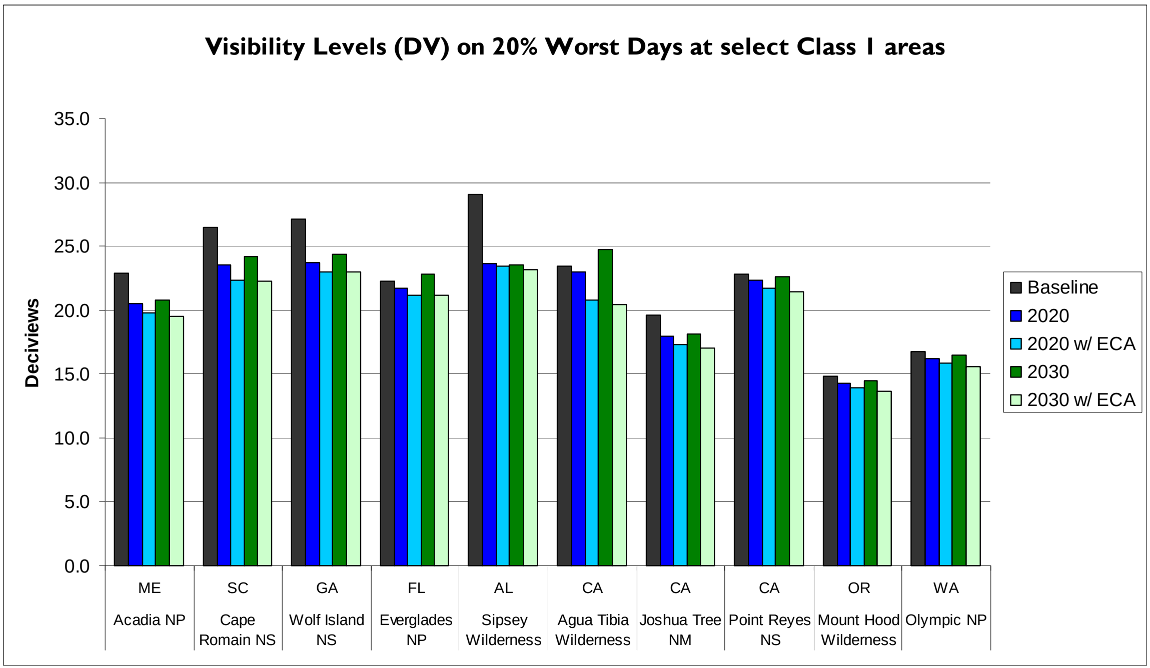

Figure 5. Bar chart of projected visibility levels in deciview units in 2002 (black), 2020 (blue), and 2030 (green). For 2020 and 2030, the projected visibility levels are shown with and without a 200 nm North American ECA.

CONCLUSIONS

The U.S. coastline and much of the interior of the country will experience significant improvements in air quality due to reduced fine particulates and ozone precursors from ships complying with ECA standards. Coastal areas will experience the largest improvements; however, significant improvements will extend hundreds of miles inland to reach nonattainment areas in states such as Nevada, Tennessee and Pennsylvania. National treasures such as the Grand Canyon National Park and the Great Smoky Mountains will also see air quality improvements. Additionally, the North American ECA is expected to yield significant health and welfare benefits. EPA estimates that the annual benefits in 2020 will include preventing between 5,500 and 14,000 premature deaths, 3,800 emergency room visits, and 4,900,000 cases of acute respiratory symptoms in 2020. More detail on the ECA modeling results is contained within the technical support document that supported the ECA designation (U.S. EPA, 2009)

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