

DEVELOPMENT OF GRIDDED OCEAN-GOING VESSEL EMISSION INVENTORIES

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ABSTRACT

Highly resolved emission inventories for ocean-going vessels are needed for air quality modeling to develop the necessary technical support for new State Implementation Plans (SIPs) for ozone, fine particles, and regional haze. Ship traffic near ports follows well-defined ship channels (routes) that can be described by navigational charts or other routes and placed in a grid, GIS, or other spatial information framework. A large-scale gridded inventory has been developed using ship positioning information and ship call activity data for ships approaching US waters. The larger scale inventory was spatially resolved along informal but usual ship routes in the open ocean generally following movements to reduce the distance between world ports. This paper describes how ocean-going vessel emission inventories can be spatially resolved near ports and in the major shipping lanes.

INTRODUCTION

Emissions inventories need to be spatially allocated in order that the data is properly input into computer models to evaluate their air quality impact. Typical allocation methods using land use or land/water coverage are inconsistent with the vessel activity.

A local scale allocation can take advantage of well-known navigational channels and vessel movement information known to local pilots. The channels into and out of ports can in some cases be precisely defined and the intended ports of call are usually also well defined spatially. This local allocation method works well for emissions generated near the port of call.

A wider scale gridded inventory for vessels operating in the open ocean has been developed using ship positioning information and ship call activity data for those vessels approaching US waters. This inventory was spatially resolved along informal but typical shipping routes in the open ocean following least distance movements between world ports.

This paper will describe how ocean-going vessel emission inventories can be spatially resolved near ports and in the major shipping lanes. Emission inventories created from a top down global approach can be compared with detailed near-port inventories to provide a seamless understanding of commercial marine emissions inventories on a broad scale.

EMISSION INVENTORY MODES

Understanding typical vessel operating modes is key to understanding how to spatially allocate the emissions. There are four general operating modes: cruising, reduced speed zone (RSZ), maneuvering, and hotelling. (ICF, 2005) The operating modes typically define the vessel operation such

as speed and engine load. Within each operating mode there can be several types of activities that might have distinct spatial allocations. These are described in Table 1.

Table 1. Large vessel operating modes.

Operating Mode	Subcategory	Spatial Description
Cruising	Operating Speed	Shipping Channel or Route
	Speed Limit Zone	Specified Link
Reduced Speed Zone	Dependent Upon Distance to Port	Several Different Speeds by Individual Link
Maneuvering	In and Out of Port	Spatially Similar
	Shifts	Movements Between Berths or Adjacent Ports
Hotelling	At Berth	By Terminal
	At Anchorage	Away from Berth

The cruise mode is typically defined as vessel movements at the design speed when the propulsion engines are operating at high loads. The cruise modes have been modeled as a steady-state mode in speed and load, though operators have been known to vary the vessel cruise speed (and therefore engine loads and emissions) depending upon delivery schedules, port congestion, weather, or other factors.

The reduced speed zone has been defined as the mode when the ship slows to improve vessel handling near land. This often occurs at the point where harbor pilots board on the way into port and disembark the vessel on the way out of port. As shown in Figure 1 for the San Francisco Bay, the Pilot Buoy defines the beginning or end of the reduced speed zone, and cruise routes into the Bay as vessels head toward or away from the Pilot Buoy. An alternative to downloading, at a cost, specific navigational charts, such as that shown in Figure 1, is to use general shipping link lanes defined by the USACE (2006), as shown by example in Figure 2, which are reasonably accurate though less precise than navigational charts. While the RSZ is usually defined as a single average speed, there can be different speeds for different navigation challenges, and so unique RSZ links could be defined to address individual vessel speeds. Some ports, in an effort to reduce emissions, are beginning to encourage or demand speed limits for vessel movement where once vessels had operated under the typical maximum cruise speed to reduce emissions. Therefore cruise mode links may become reduced speed zone links for the purposes of air quality.

Figure 1. San Francisco Bay entrance navigational chart.

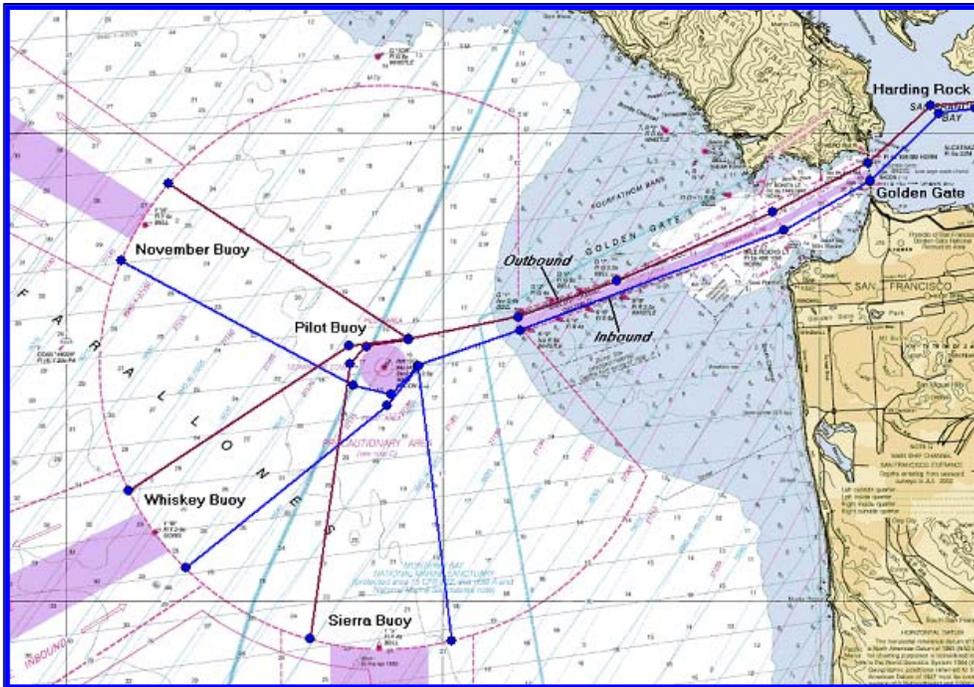
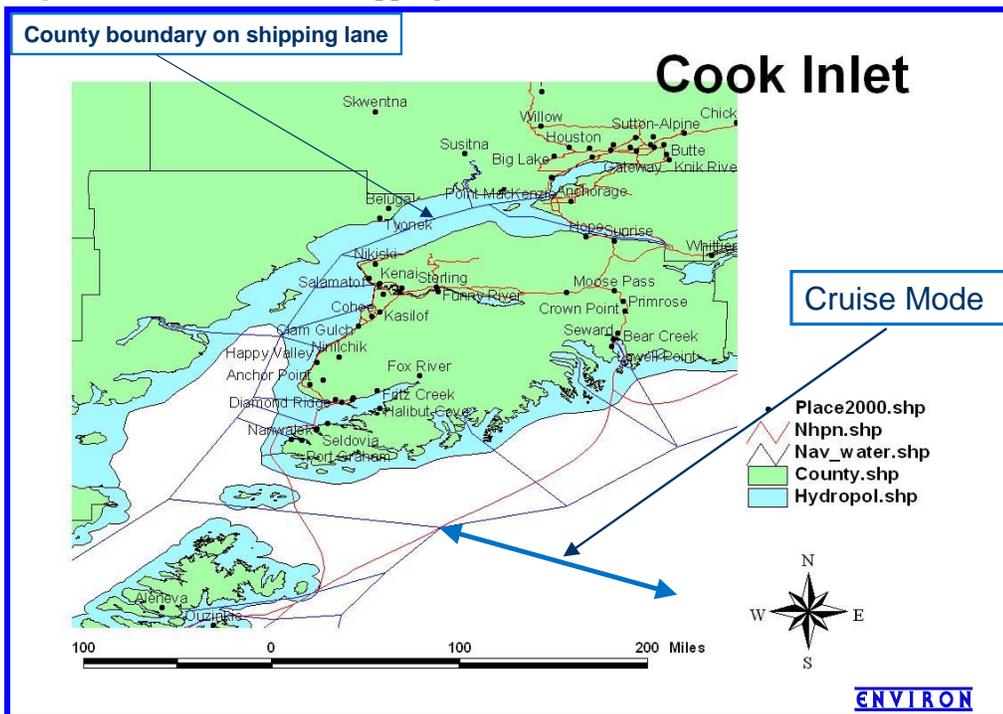


Figure 2. USACE (2006) shipping channel for Cook Inlet, Alaska.



The maneuvering zone is usually defined within a short distance of the berths and so can also be placed spatially within a gridded regional inventory using the port boundaries. Shifts between berths can be similar to maneuvering modes in that the propulsion engine can be used to shift or maneuver the vessels between berths or to nearby ports.

Hotelling modes include emissions associated with the vessels at berth though vessel can also hotel when lying at anchor while waiting for a berth, refueling, or the next assignment. Berths are usually well defined, but some vessels can unload at locations well away from a berth such as tanker that unload into off-shore pipelines. Anchorage locations can be some distance from the port berths. Hotelling at anchorage is not typically an important operating mode and is usually limited to bulk carriers and tankers unless the port is unusually busy and the intended berth is occupied. Most port emissions inventories to date have not distinguished hotelling at anchorage from that at berth, so spatial allocation has been assumed to be entirely at berth. Vessel usually anchor close to the destination berths, so the misallocation for ships hotelling at anchor should not affect regional modeling significantly, but the precision of the spatially allocation for this mode remains a consideration for more detailed evaluations.

Local Scaled (Port Specific) Spatial Allocations

For near port spatial allocations, the port berths and routes to and from those berths can be spatially identified using existing geographic definitions of the port boundaries. The transit routes (cruise and reduced speed zone modes) can use one of two methods for spatial allocations described here.

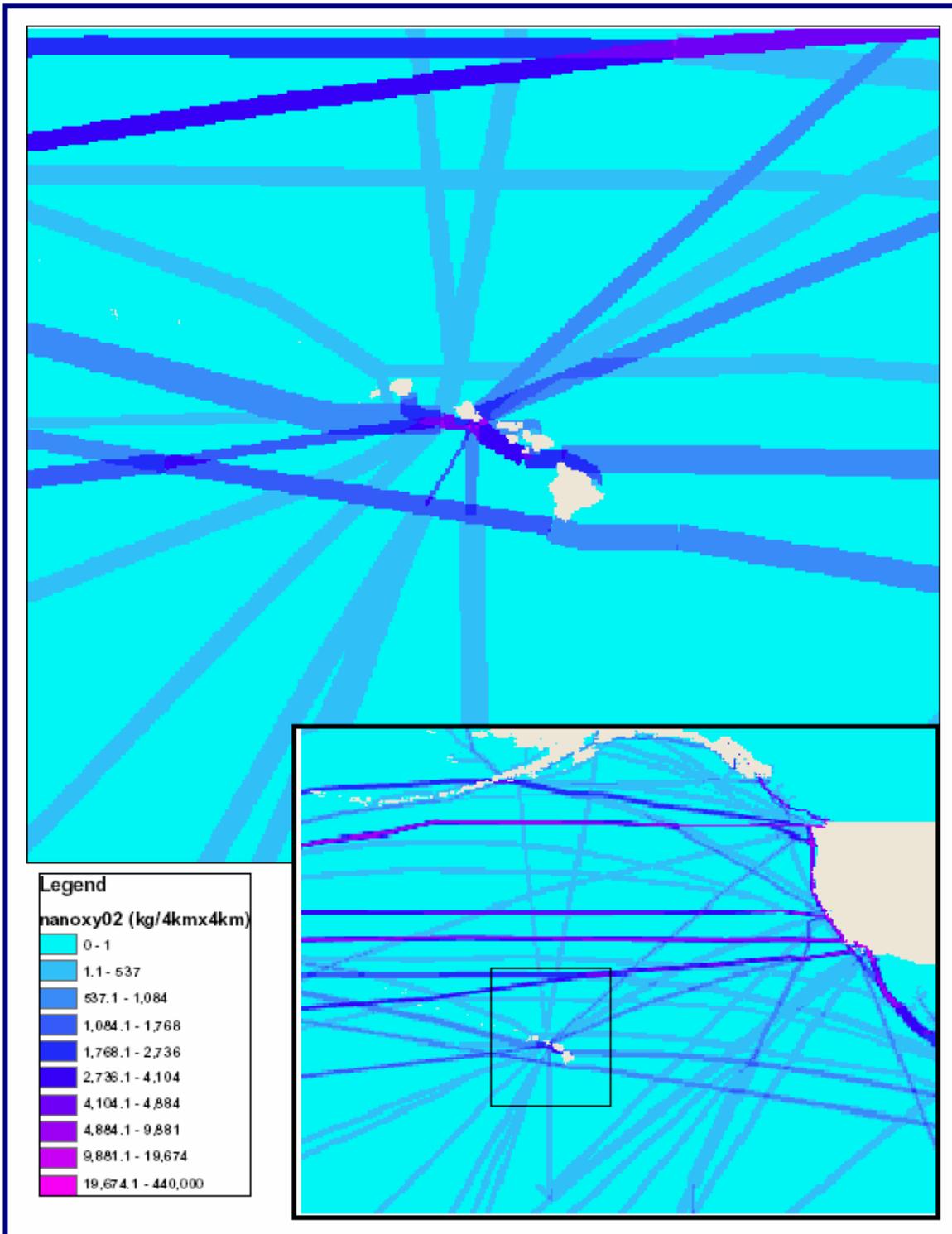
The reduced-speed zone follows well-defined ship channels (routes) that can be described by navigational charts and placed in a grid using GIS or another spatial framework. Either navigational charts (Figure 1) or more general shipping lane links (Figure 2) can be used to map the reduced speed zone emissions along the route to the open ocean cruise mode. When using navigational charts, the pilot boarding point can be well defined as shown in Figure 1 as the Pilot Buoy, and used to distinguish between the cruise and reduced speed zone links. For the more general shipping link estimates in Figure 2, the cruise mode link description is less well defined, but a reasonably appropriate definition would be the boundary between the shipping link and the open ocean as marked in Figure 2.

Wide Scaled (Open Ocean) Spatial Allocations

Recent work (Corbett, 2006) was completed to detail shipping routes in the open ocean well away from ports. This method describes emissions from vessels operating at cruise mode but outside of well-defined shipping channels near port entrances.

The inventory was estimated spatially using the Waterway Network Ship Traffic, Energy and Environment Model (STEEM), which characterizes ship traffic, estimates energy use, and assesses the environmental impacts of shipping. STEEM uses an empirical waterway network based on shipping routes revealed from observed historical ship locations. The ship traffic module of STEEM geographically and temporally describes ship traffic based on an empirically derived waterway network, historical ship movement data, and ship attributes data. Applications of STEEM include producing spatially-resolved energy and emissions inventories, assessing the impacts of shipping activities on the environment (e.g. invasive species carried by ballast water), interaction between ships and marine mammals, evaluating navigation safety, and other potential uses (e.g. logistics planning and disaster response planning). Figure 3 shows an example of the results of the STEEM model for the Pacific Ocean and specifically around Hawaii.

Figure 3. STEEM model results for the Pacific.



It is important to understand that the open ocean inventory was developed for vessels operating under constant speed conditions. Therefore vessel movements near ports especially operating below the cruise speed conditions need to be adjusted for the lower load conditions. Accurate vessel movement data near ports is usually available, so the STEEM model is currently best used to describe vessel movement well away from shore.

Conclusions and Future Work

This work describes the most recent advances in spatially allocating emissions from large, deep-draft, ocean-going commercial marine vessels. The precision of the spatial allocation near ports is restricted to that of the activity data used to estimate the emissions from these vessels. If vessel movements can be described more precisely, then the spatial allocation can be more detailed.

The approach might be extended to incorporate small vessel types including tug and barge operations, though these sources visit a larger number of ports and therefore use more numerous routes.

Acknowledgements

This paper outlines work conducted under various funding sources including the California Air Resources Board (ARB), Western Regional Air Partnership (WRAP), Improvement - State and Tribal Association of the Southeast (VISTAS), and the Environmental Protection Agency (EPA).

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Keywords:

Commercial marine

Off-road

Nonroad

Mobile sources

Spatial allocation