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Ammonia Bunkering Spill Scenarios: Modelling Plume's Behaviour and Potential to Trigger Harmful Algal Blooms in the Singapore Straits

Authors : Bryan Low

Abstract : In the coming decades, the global maritime industry will face a most formidable environmental challenge -achieving net zero carbon emissions by 2050. To meet this target, the Maritime Port Authority of Singapore (MPA) has worked to establish green shipping and digital corridors with ports of several other countries around the world where ships will use low-carbon alternative fuels such as ammonia for power generation. While this paradigm shift to the bunkering of greener fuels is encouraging, fuels like ammonia will also introduce a new and unique type of environmental risk in the unlikely scenario of a spill. While numerous modelling studies have been conducted for oil spills and their associated environmental impact on coastal and marine ecosystems, ammonia spills are comparatively less well understood. For example, there is a knowledge gap regarding how the complex hydrodynamic conditions of the Singapore Straits may influence the dispersion of a hypothetical ammonia plume, which has different physical and chemical properties compared to an oil slick. Chemically, ammonia can be absorbed by phytoplankton, thus altering the balance of the marine nitrogen cycle. Biologically, ammonia generally serves the role of a nutrient in coastal ecosystems at lower concentrations. However, at higher concentrations, it has been found to be toxic to many local species. It may also have the potential to trigger eutrophication and harmful algal blooms (HABs) in coastal waters, depending on local hydrodynamic conditions. Thus, the key objective of this research paper is to support the development of a model-based forecasting system that can predict ammonia plume behaviour in coastal waters, given prevailing hydrodynamic conditions and their environmental impact. This will be essential as ammonia bunkering becomes more commonplace in Singapore's ports and around the world. Specifically, this system must be able to assess the HAB-triggering potential of an ammonia plume, as well as its lethal and sub-lethal toxic effects on local species. This will allow the relevant authorities to better plan risk mitigation measures or choose a time window with the ideal hydrodynamic conditions to conduct ammonia bunkering operations with minimal risk. In this paper, we present the first part of such a forecasting system: a jointly coupled hydrodynamic-water quality model that can capture how advection-diffusion processes driven by ocean currents influence plume behaviour and how the plume interacts with the marine nitrogen cycle. The model is then applied to various ammonia spill scenarios where the results are discussed in the context of current ammonia toxicity guidelines, impact on local ecosystems, and mitigation measures for future bunkering operations conducted in the Singapore Straits.

Keywords : ammonia bunkering, forecasting, harmful algal blooms, hydrodynamics, marine nitrogen cycle, oceanography, water quality modeling
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