PHOTOCHEMICAL MODELING OF AN INDUSTRIAL CITY IN QATAR

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INTRODUCTION

The Ras Laffan Industrial City (RLIC) is located 80 km north of Doha and forms the heart of Qatar’s natural gas industry (Figure 1). Covering 106 km², RLIC is home to major companies such as RasGas, Shell Gas & Chemicals, as well as additional companies in the future. In recent years, monitoring has indicated that ozone concentrations in communities downwind of RLIC are exceeding standards set by the State of Qatar. Therefore, as a permit condition for expansion at RLIC, Qatar’s Supreme Council for the Environment and Natural Resources (SCENR) required that a photochemical grid modeling analysis be performed to assess RLIC’s contributions to ozone concentrations in the region.

Stationary source emissions data were obtained from the inventory developed by URS Corporation. URS provided an emission inventory spreadsheet designed to calculate atmospheric emissions from stationary sources in the region surrounding RLIC and Al Khor. The spreadsheet was populated with existing information about stationary sources and allowed users to enter new sources, modify existing sources, and generate graphical and tabulated emissions summaries from a selection of sources, facilities, and regions. The inventory included current and planned emissions sources.

URS also prepared a mobile source emission inventory for RLIC. The mobile source inventory was intended to estimate emissions from mobile sources in the Ras Laffan air shed. The air shed generally covers the area between Al Khor and RLIC. The majority of the mobile sources identified in this study were believed to be associated with operations inside RLIC. However, other sources were included if their activity data could be characterized and estimated.

Photochemical modeling was performed with the Comprehensive Air Quality Model with Extensions (CAMx). The photochemical domain covered the entire State of Qatar as shown in Figure 1 and was defined to cover an area of 248 km² with 49, 104 km cells. The domain included a large portion of the Arabian Gulf and was made as large as possible without extending into other countries. The domain was defined in Lambert Conformal coordinates to ensure compatibility with the MMM meteorological model. The CAMx domain had 12 vertical layers.

RESULTS

A scatterplot of oxides of nitrogen (NOx) concentrations by wind direction at the ALSH monitor for the second model- ing period is shown in Figure 3. Three other clusters showed higher NOx concentrations: when the winds were from the west (260 degrees), the southwest (210 degrees), and the southeast (140 degrees). These clusters are annotated on Figure 3. When vectors are drawn to ALSH from these directions, as shown in Figure 4, the relationship between the two regions and NOx concentrations measured at ALSH become apparent: cluster 1 is associated with sources in Bahrain (and possibly sources in Saudi Arabia); cluster 2 is associated with sources in the industrial city of Duhail; and cluster 3 is associated with sources in the RLIC.

Data Analysis Findings

• Both the 1-hr and 8-hr ozone standards are exceeded in the Ras Laffan area. The 8-hr standard appears to be exceeded more often than the 1-hr standard. During the periods reviewed (which unfortunately did not include July 2004), one 1-hr and eight 8-hr ozone standard exceedances occurred.

• Background ozone concentrations (when winds are consistently from the north) measured at the ALSH monitoring site can exceed the 8-hr standard, which implies that there may be significant regional contributions to observed ozone concentrations. During February 2005, a 1-hr ozone concentration of 120 ppb was measured at ALSH.

• NOx concentrations at ALSH were often above 5 ppb under northerly winds, which indicates that air upwind of Qatar is not clean.

• NOx concentrations at ALSH show a correlation with wind direction. The highest concentrations were observed when the winds were from the direction of Dukan but, on average, the concentrations were higher when the winds were from northern Bahrain and Ad Dammam. The third highest concentrations were observed when the winds were from the direction of Ras Laffan. The correlation between NOx concentrations in northern Qatar and transport from known emission source areas highlights the importance of expanding the emission inventory for photochemical modeling.

• Transport distances of 100 to 200 km per day were observed during ozone episodes; thus, the potential for regional contributions to ozone is significant. Based on analysis of observed winds, transport distances of 100 km or more per day were likely during the August episodes and more than 200 km per day during the November episodes.

PHOTOCHEMICAL MODELING

Two periods were selected for analysis. The first period selected was August 23-30, 2004, which included two days on which peak observed 1-hr ozone concentrations approached the state standard of 120 ppb (at Ras Laffan City site (RLAC) — 113 ppb on August 26 and 119 ppb on August 29. The second period was November 25-28, 2004, with a peak 1-hr ozone concentration of 118 ppb in Al Khawr (ALKH) on November 27. Air quality data from two sites in the Ras Laffan region, RLAC and ALKH, were available for the August 23-30, 2004 period. The RLAC site is located in the southeast of the study area, while the ALKH site is located on the north side of the city of Al Khor at the edge of a housing community.

Meteorological modeling was performed with the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model, Version 5 (MM5) on the three domains shown in Figure 2. The outer domain consisted of 93 x 63 24 km cells. The intermediate domain consisted of 79 x 79 12 km cells. The inner domain consisted of 73 x 73 4 km cells. Each domain had 34 vertical levels extending from the surface to approximately 14 km.

Table 1. Comparison of observed and predicted peak 1-hr ozone concentrations for the two modeling periods.

Photochemical modeling of the RLIC emissions only produced peak concentrations that were 12 to 15 ppb above background (boundary) concentrations.

Ozone is underpredicted by the modeling system, in part, because of the domain size. On several of the days modeled, it was evident that emissions reached the modeling domain boundary before winds changed and brought emissions and ozone back to the RLIC area. Ozone is underpredicted by the modeling system, in part, because not all emissions sources in the domain are included in the model. It is evident from the modeled transport that emissions from areas outside of RLIC may contribute to the formation of ozone that eventually affects the RLIC area.

Ozone is underpredicted by the modeling system, in part, because transport of ozone and ozone precursors were not modeled and could not be addressed by boundary conditions alone. Without specific measurements at many locations along the modeling domain boundary, adjusting boundary conditions to represent sources outside the domains tends to result in under- or overpredictions.

Ozone concentrations at some sites in northern Qatar are significantly lower than at other sites in the region. The response of the modeling system to VOC and NOx reductions indicates that the modeled atmosphere is VOC-limited, which is consistent with the large NOx emissions in the RLIC inventory.

VOC and NOx reductions will likely increase ozone concentrations due to high levels of NOx reduction. However, smaller NOx reductions may be effective at reducing regional ozone concentrations downwind of RLIC. In VOC-limited atmospheres, NOx reductions tend to increase ozone near the source area due to reduced ozone lifetime. However, NOx reductions, provided the “building blocks” for ozone, NOx, and VOC reductions, even under VOC-limited conditions, will reduce ozone concentrations at some distance downwind of the source.

Inclusion of other regional sources may significantly change the conclusions of this study. It is apparent that significant amounts of NOx are being transported into northern Qatar. If NOx is the only ozone precursor being transported into the region, we expect that the conclusions about emission controls will prevail. However, if significant amounts of VOCs are being transported into the region, the conclusions may differ.

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