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Vehicle Emissions from Sultan Qaboos University in Oman: Line Source Case Study

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Abstract**:** *The aim of the study was to predict concentration levels of carbon monoxide (CO), carbon dioxide (CO_2), and nitric oxide (NO_x), three of the most dominant vehicle emission pollutants, at Sultan Qaboos University, located in Muscat, Sultanate of Oman. The study focused on modeling and investigating the dispersion of CO, CO_2, and NO_x for a street located within the university's boundaries. CALPUFF simulation results clearly demonstrated that CO concentrations were within acceptable levels as defined by United States Environmental Protection Agency (EPA) standards. On the other hand, the concentration levels of both CO_2 and NO_x significantly exceeded the allowable limits assigned by the EPA's emission standards*.

Keywords: *line source, CALPUFF, vehicle emitted pollutants, Sultanate of Oman*

1. Introduction

Developed by the Atmospheric Studies Group, CALPUFF (TRC Environmental Corporation, Export, Pennsylvania, USA) is considered one of the most powerful environmental modeling programs. In addition to the fact that it can be run for any location around the world for any modeling type period, CALPUFF has attracted researchers undertaking various studies in past years [1-7]. Among recently conducted studies, few have considered investigating the dispersion of CO, CO_2, and NO_x or their concentration levels. No known published studies model the application of CALPUFF in the dispersion of the three mentioned pollutants from vehicles. This research paper seeks to add to the literature by investigating the effect of vehicle emissions on SQU's environment assisted by CALPUFF software. The CO, CO_2, and NO_x dispersion and concentration levels for a street located within SQU's boundaries were modeled and simulated for 2014. Along with the collected data related to vehicle emissions, CALPUFF modeling software was used to assess the air quality impact of CO, CO_2, and NO_x during the selected year.

2. Materials and Methods

2.1. Area of study

Considered the first public university in the Sultanate of Oman, Sultan Qaboos University (SQU), located in Muscat, Oman, was established in 1982 and began enrolling students in 1986. Initially just 557 students attended the institution, but currently around 15,000 are enrolled. The number of vehicles within SQU's boundaries also has tremendously increased which, as a result, causes traffic jams. In addition to commuters, the academic staff and female students who live inside the university's campus are considered contributors to the traffic jam issue. Compounding this problem is SQU Hospital, an educational and medical institution also located within the university's boundaries and officially opened in 1990 (area = 40,000 m^2). As both genders concentrate in the streets located within SQU's boundaries at the end of each teaching session (e.g., noon for a class that starts at 10:00 a.m. and ends at noon), the traffic jam issue is one that extends beyond car use on campus. The study will consider the street where most students are located as a line source (Figure 1).

Fig. 1: Line source case study street location with the associated traffic jam.

2.2. Calpuff Modelling System

TABLE I: Model Input Information for the Study Domain

Parameter	SQU-specific data points
Projection type	LCC
LCC latitude of origin	23.590828 °N
LCC longitude of origin	58.163697 °E
Latitude 1	5 N
Latitude 2	45 N
False easting	0
False northing	0
Continent/ocean	Global
Geoid-ellipsoid separation	WGS-84:WGS84
Region	WGS-84
DATUM code	WGS-84
X (easting)	-100 km
Y (northing)	-100 km
Number of grid cells (X)	200
Number of grid cells (Y)	200
Grid spacing	1 km
Number of vertical layers	9
Cell face heights	0, 20, 50, 100, 150, 200, 300, 500, 1000, 2000 m
Base time zone	UTC + 04:00

Calpuff is air quality and meteorological modelling software used to investigate and model air pollution dispersions and concentration levels for various types of sources [8]. Before running the CALPUFF pre-processors, the meteorological grid's shared information was inserted into a common file using the identify shared information module. This information was shared amongst all CALPUFF processors (Table 1).

2.3. Upper air and surface meteorological data

Upper air meteorological data information was extracted out of the listed radiosonde stations in the National Oceanic and Atmospheric Administration's official website (esrl.noaa.gov/raobs/). For a full period, 12-hour interval data were obtained from the upper air climate station. The extracted data were processed in a format compatible with CALPro's READ62 program to produce an UP.DAT file suitable as an input to CALMET. On the other hand, the surface meteorological data used in this study were obtained from the Directorate General of Meteorology and Air Navigation in Oman (www.met.gov.om). The hourly meteorological data consist of the following information: precipitation (mm), temperature (ºC), station pressure (mbar), wind direction (º), wind speed (m/s), relative humidity (%), cloud cover (tenths), and cloud height (ft). For a full period similar to that of the upper air data period, the obtained data were prepared in a format that could be run using CALPro's SMERGE program to produce a SURF.DAT file suitable for input into CALMET. The extracted information related to upper air and surface stations is summarized in Table 2.

TABLE II: Upper Air and Surface Stations Information

Parameter	Radiosonde station (upper air meteorological data)	Surface station (surface meteorological data)
Station name	ABU DHABI INTL 99 AE	SEEB INTL/MUSCAT 99 OM
INIT	OMAA	OOMS
UTM latitude	24.43 °N	23.58 °N
UTM longitude	54.65 °E	58.28 °E
Location X on grid	-400 km	10 km
Location Y on grid	60 km	12 km
Station elevation	27 m	17 m
WMO ID	41217	41256
WBAN	99999	99999

2.4. Emission data

In order to calculate the emission rates for line source, emission factors are required. Emission rates differ in terms of vehicle specifications (e.g., engine capacity, fuel type, etc.), speed, and weight according to vehicle type. Numerous environmental institutes and research papers have concentrated their efforts in calculating emission rates. The Transport Research Laboratory [9] developed a Microsoft Excel spreadsheet (Microsoft, Corp., Redmond, Washington, USA) that categorizes vehicles based on certain specifications (e.g., weight, engine capacity, etc.), emission standards, and vehicles' average speeds for various pollutants (https://www.gov.uk/government/publications/road-vehicle-emission-factors-2009). For this study, the emission factors used were taken from Transport Research Laboratory [9] and summarized in Table 3.

TABLE III: Vehicle Emission Factors [9]

Pollutant	Vehicle specifications	Emission factor
CO (g/veh.km)	Vehicle speed at 34.5	15.74
CO_2 (g/veh.km)	km/hr, petrol, pre-euro	182.35
NO_x (g/veh.km)	standard, <1400 cc, <2.5t	1.29

2.5. Domain area

The main focus of the current article was to study the effect of vehicle emissions on a line source, defined as a street located within SQU, based on statistical data collection conducted from April 1-3, 2014, between 11:30 a.m. and 12:30 p.m. (Table 4). Within the study period, the greatest number of vehicles passed through on April 2, 2014 (n = 1,042). Based on assumed average speed and the total number of cars passing through the located street for the specified modelling day, emission rates of CO, CO_2, and NO_x were calculated (Table 5). CALPUFF line source input parameters, which include the street coordinates with respect to the located origin, emission height, car width, building dimensions, and the separation between each building are listed in Table 6.

TABLE IV: Statistical Data Collection for the Average Number of Cars Entering the Investigated Street

Selected days	Timing 11:30 am-12:30 p.m.
Day 1 (1/4/2014)	1,013
Day 2 (2/4/2014)	1,042
Day 3 (3/4/2014)	1,006

TABLE V: Line Source Emission Rate Calculation for the Desired Pollutants on April 2, 2014

Pollutant	Emission factor g/veh.km	Average speed km/h	Number of vehicles for selected day veh	Emission rate g/s
CO	15.74	34.5	1,042	157.187
CO_2	182.35	34.5	1,042	1820.946
NO_x	1.29	34.5	1,042	12.928

TABLE VI: CALPUFF Line Source Input Parameters

Parameter	Values
X (start)	0 km
Y (start)	0.24 km
X (end)	0 km
Y (end)	-0.19 km
Emission height	0.35 m
Car width	1.4 m
Building height	30 m
Separation between buildings	40 m
Base elevation	55.4736 m
Building width	120 m
Building length	30 m

3. Results and Discussion

Muscat is a coastal city, and the sea strongly affects meteorological conditions. The five highest one-hour average concentrations of CO and NO_x and the five highest 0.5-hour average concentrations for CO_2 simulated for April 2, 2014, from 00h00 to 23h00 are listed in Table 7. All these concentrations were located 0.5 km east and 0.5 km south of SQU's defined origin, still within the university's boundaries. These top concentrations occurred between 19h00 and 01h00. The highest concentration occurred at 19h00, the second highest occurred at 20h00, the third occurred at 01h00, the fourth occurred at 21h00, and the fifth highest concentration occurred at 22h00.

Table 7 also demonstrates a comparison between the maximum highest average CO, CO_2, and NO_x concentration levels and their respective criterion limits. CO and NO_x pollutants have one-hour maximum allowable concentration levels of 40,096.1 µg/m^3 (35 ppm) and 188.2 µg/m^3 (100 ppb) respectively, according to the standards of United States Environmental Protection Agency [10]. As for CO_2, the 0.5-hour maximum concentration criterion is around 63,000 µg/m^3 [11]. Table 7 shows that the simulated one-hour average CO concentrations were still within the United States Environmental Protection Agency one-hour criterion limits [10]. As for the remaining pollutants, NO_x concentrations were found to significantly exceed their respective one-hour allowable limits. Similarly, the simulated 0.5-hour average CO_2 concentrations were found to be above its 0.5-hour limit. Given the fact that Muscat is located close to the sea, slight changes in seasonal weather patterns may cause CO, CO_2, and NO_x concentrations to exceed even the highest concentration levels specified in this study. Figure 2, Figure 3, and Figure 4 represents the plume trajectories of the maximum concentrations of CO, CO_2, and NO_x respectively.

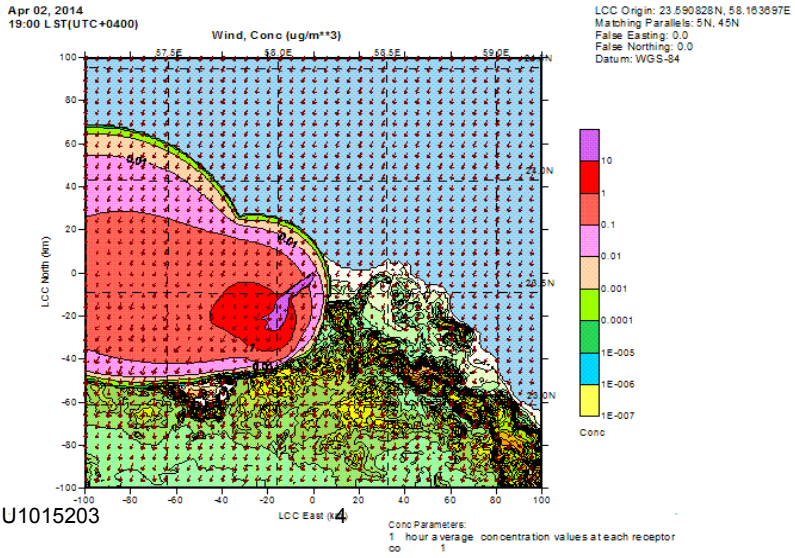

Fig. 2: Wind and maximum concentration distribution of CO in Sultan Qaboos University.

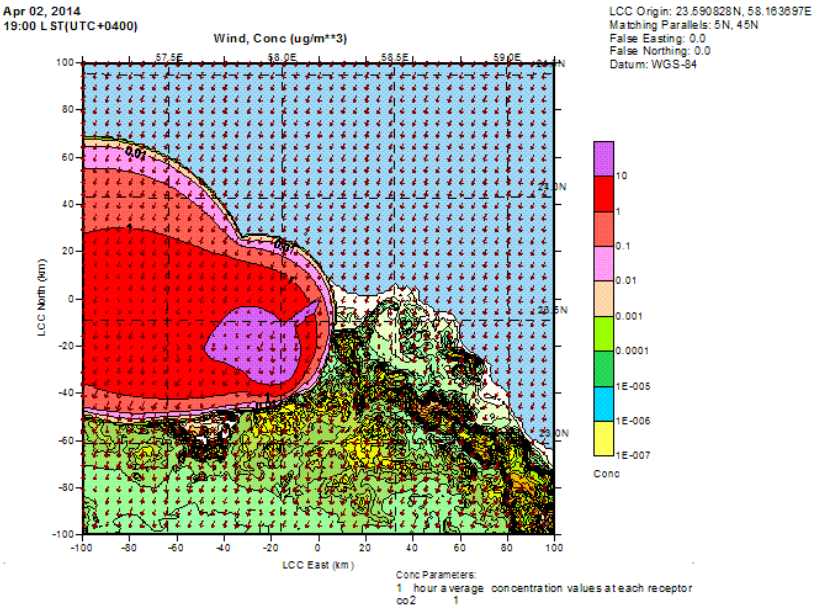

Fig. 3: Wind and maximum concentration distribution of CO_2 in Sultan Qaboos University.

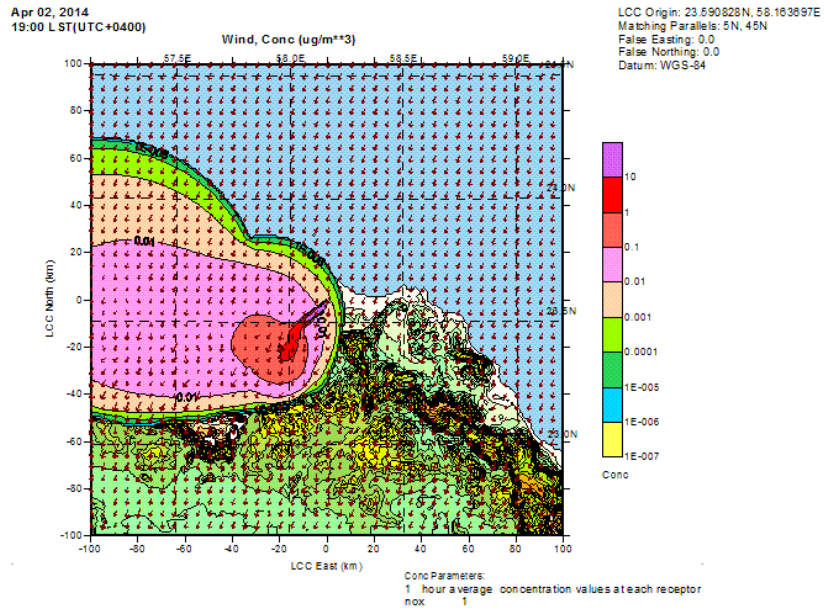

Fig. 4: Wind and maximum concentration distribution of NO_x in Sultan Qaboos University.

TABLE VII: The Line Source's Top Five Average CO, CO_2, and NO_x Concentrations Simulated on April 2, 2014

Coordinates (km)	Time (HH:MM)	Average peak values ($\mu g/m^3$)		
		CO* 1-hour	CO_2** 0.5-hour	NO_x*** 1-hour
0.5, -0.5	19:00	16,441	218,943.6	1351.4
0.5, -0.5	20:00	6836.8	91,045.1	561.97
0.5, -0.5	01:00	6802.4	90,587.4	559.14
0.5, -0.5	21:00	5881.6	78,325.2	483.45
0.5, -0.5	22:00	5323.5	70,893.1	437.58

*Allowable 1-hour average concentration is 40,096.1 µg /m^3 (35 ppm) according to the United States Environmental Protection Agency [10]

**Allowable 0.5-hour average concentration is 63,000 µg/m^3 according to Ontario Ministry of the Environment [11]

***Allowable 1-hour average concentration is 188.2 µg/m^3 (100 ppb) according to the United States Environmental Protection Agency [10]

4. Conclusion

In order to assess the maximum ground level concentrations of CO, CO_2, and NO_x emitted from traffic emissions in SQU, the CALPUFF dispersion modelling system was utilized. The simulation results associated with the dispersion models were evaluated against the CO, CO_2, and NO_x criterion limits. The simulated one-hour average CO concentrations were within the allowable limits. On the other hand, the one-hour average NO_x and 0.5-hour average CO_2 concentrations were found to significantly exceed their respective concentration limits. The recorded maximum concentrations occurred at the same locations within SQU's boundaries, which may be related to the possibility that the wind blowing from the sea significantly affected the dispersion of the three targeted pollutants. As a result, CO, CO_2, and NO_x accumulated nearby. It is recommended that external parking slots away from the campus be provided for students of both genders and, from these slots, students can take a bus to facilities within SQU. Such a policy would ensure that fewer pollutants accumulate within the university compound, potentially affecting the health of all on campus.

5. References

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