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Investigating the impact of monsoon season on the dispersion of pollutants emitted from vehicles: A case study of Salalah City, Sultanate of Oman

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ABSTRACT

The paper concentrates on utilizing CALPUFF to model and investigate the impact of the monsoon season on the dispersion of carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NO_x) emitted from vehicles. During monsoon season, traffic jams have become an important issue in Salalah, Oman, due to a rapid increase in visitors to Salalah at that time of the year. Therefore, the main aim of the current work is to evaluate the region's concentrations of CO, CO_2, and NO_x during monsoon season and compare them with non-monsoon season levels. The CALPUFF simulation analysis was based on selected modeling days for both monsoon and non-monsoon seasons. The modeling periods' meteorological conditions were multifarious. Thus, as a result, concentration levels, as well as the coordinates where concentrations exceeded the criterion limits, differed. Seasonal comparisons revealed that concentration levels of CO, CO_2, and NO_x during the monsoon season were greater than the levels associated with the modeling days during the non-monsoon season.

1. Introduction

Over the past years, there has been a dramatic increase in traffic on roads worldwide. This rapid increase has led to enormous emission of various pollutant gasses into the atmosphere. Examples of these vehicle-emitted pollutants include carbon monoxide (CO), carbon dioxide (CO_2), and nitrogen oxides (NO_x). According to World Health Organization (2005), transport-related air pollution contributes to an increased risk of death, especially from cardiopulmonary causes. It also increases the risk of respiratory symptoms and diseases that are not associated with allergies.

Given recent increases in transport-related air pollution loads, there is a severe need for accurate, reliable air quality prediction models in order to reduce or at least maintain environmental and human exposure to vehicle-emitted pollutants. Considered an effective modeling program in the environmental field, CALPUFF is a Gaussian puff model designed by the Atmospheric Studies Group (ASG) in order to provide an accurate simulation for the dispersion of pollutants, along with their concentration levels, for complex terrain domains. Many researchers have been attracted by the flexibility that CALPUFF provides, such as the ability to select

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locations and modeling periods.

Different CALPUFF case studies have assessed pollutant concentrations for different locations worldwide within recent years. Liao et al. (2014) conducted an uncertainty analysis of ecological risk assessment caused by heavy-metal deposition from municipal solid waste incineration (MSWI) plants. CALPUFF was employed to simulate the ground-level atmospheric concentrations of lead (Pb) and cadmium (Cd) from MSWI plants. Zhang et al. (2014) applied the CALPUFF air quality model to study the effect of the long-range transport of air pollutants on the atmospheric environment in the Guanzhong region of Shaanxi Province. On the other hand, Feng et al. (2014) investigated the effects of air transportation on air quality in the Zhoushan Islands in China by applying the MM5/CALPUFF modeling system. Souto et al. (2014) focused on applying the CALPUFF model in order to simulate the dispersion of sulfur dioxide (SO_2) emitted from a coal-fired power station while taking into account both different stack configurations and meteorological inputs. To model the dispersion for SO_2, multiple research papers have been recently published that employed CALPUFF (Abdul-Wahab et al., 2011a, 2011b, 2012). Wu and Nelson (2014) focused on assessing and simulating the atmospheric movement of pollutants emitted from a potential post-combustion carbon capture project.

Different case studies, such as those of Prueksakorn et al. (2014), Murguia et al. (2014) and Sówka et al. (2014), employed CALPUFF software to investigate the concentration levels of odors. On the other hand, Krajčovičová et al. (2014) and Ivančič and Vončina (2014) focused on assessing the concentration levels of particulate matter. Research papers published by Abdul-Wahab et al. (2013) and Gurram et al. (2014) focused on modeling the dispersion of nitrogen oxides (NO_x). Case studies by Nagendra et al. (2016), Abdul-Wahab et al. (2015), and Lee et al. (2014) are examples in which CALPUFF software was employed for simulating concentration levels for multiple pollutants.

Salalah City, located in Oman's Dhofar Governorate, is one of only two places on the Arabian Peninsula (besides Yemen) that experiences a monsoon season. A monsoon is a seasonal change in the direction of the prevailing, or strongest, winds of a region. Monsoons are most often associated with the Indian Ocean, where winds blow from cold to warm regions. Between mid-June and mid-August, monsoon clouds from India bring a constant sprinkling of rain to the city As a result, the impact of the monsoon season on Salalah is reflected through its moderate climate and shiny green landscapes. Both locals and tourists from all over the world visit Salalah during this season. In recent years, the number of visitors to Salalah has rapidly increased. According to the National Center for Statistics and Information (NCSI) (www.ncsi.gov.om), it has been recorded that the visitors during the monsoon season for the year 2014 were approximately 431,105 visitors compared to 351,195 visitors recorded in 2012. As a result of this increase, the number of vehicles within Salalah has also increased tremendously, causing severe traffic jams in the region.

While many published papers have been devoted to modeling the dispersion of vehicle-emitted pollutants (Joo et al. 2017; Hatzopoulou and Miller 2010; Abdul-Wahab and Fadlallah 2014), only a few, including the works of Ravindra et al. (2003) and Majumdar et al. (2010), have focused on studying the effect of vehicle emissions and the dispersion of CO, CO_2, and NO_x concentrations during monsoon seasons. In addition, the previously mentioned studies considered India as their case study domain. Thus, no previous studies have investigated the effect of the monsoon season on the dispersion of CO, CO_2, and NO_x concentrations emitted from vehicles in Oman and, specifically, Salalah. Because traffic jams during Salalah's monsoon season have become an important issue in the region, the main aim of this paper was to utilize CALPUFF to model and evaluate the concentrations of CO, CO_2, and NO_x emitted from vehicles in Salalah during monsoon season and compare them with the levels experienced during non-monsoon seasons.

2. Materials and methods

2.1. Description of area of study

With a population of 321,290 according to the 2014 survey conducted by NCSI, Salalah, the capital of the Dhofar Region and the country's second largest city, is located in the southern region of Oman (Fig. 1). The map in Fig. 1 shows the mountainous terrain around Salalah with its varying elevations. Fig. 2 depicts Salalah's domain of study bounded by a polygon using Google Maps. The polygon coordinates are illustrated in Table 6. Salalah's area covers approximately 2916 km^2.

2.2. CALPUFF modeling system

CALPUFF is an air quality and meteorological modeling software package used to investigate and model air pollution dispersions and concentration levels for various sources (Scire et al., 2000). The software mainly consists of three components: CALMET, CALPUFF, and CALPOST. CALMET is a diagnostic model system used to generate meteorological data for temperature and wind fields. These data points are placed on a three-dimensional (3D) gridded domain. CALMET requires geophysical data for the selected area of study as well as predicted or location-dependent observational data, such as upper air and surface meteorological data obtained from weather stations located within the desired domain of study. Moving to CALPUFF, it is an air quality model used to process the dispersion and chemical transportation of air pollutants emitted from different kinds of sources. CALMET's processed output data file is essential for the operation of CALPUFF.

CALPOST is a crucial tool that processes the output data files generated from CALPUFF and provides simulation results for maximum concentration levels of the selected pollutants.

In the current study, before running the CALPUFF pre-processors, the meteorological grid's shared information, listed in Table 1, was inserted into a common file using the identified shared information module. This information was shared amongst all CALPUFF processors. Simulations were run on a 16-bit Windows XP computer with an Intel Pentium 4 3.4 GHz processer, 1 GB RAM. CALPUFF modeling system's fractional convergence criteria for numerical slug sampling integration and numerical area source integration