Atmospheric Research 197 (2017) 84–93

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmosres

Assessment of a CFD model for short-range plume dispersion: Applications to the Fusion Field Trial 2007 (FFT-07) diffusion experiment

Pramod Kumar*, Sarvesh Kumar Singh, Pierre Ngae, Amir-Ali Feiz, Grégory Turbelin

LMEE, Université d'Evry Val-d'Essonne, 40 Rue Du Pelvoux, Courcouronnes 91020, France

ARTICLE INFO

Keywords:
CFD modelling
FFT-07 field experiment
Fluidyn-PANACHE
Short-range plume dispersion

ABSTRACT

Simulations of the short-range plume dispersion under different atmospheric conditions can provide essential information for the development of source reconstruction methodologies that allows to retrieve the location and intensity of an unknown hazardous pollutant source. This process required a comprehensive assessment of the atmospheric dispersion models with tracer diffusion experiments in various stability conditions. In this study, a comprehensive evaluation of a CFD model fluidyn-PANACHE is performed with the observations from available seven trials of single releases conducted in the Fusion Field Trail 2007 (FFT-07) tracer experiment. The CFD simulations are performed for each trial and it was observed that the CFD model fluidyn-PANACHE provides good agreement of the predicted concentrations with the observations in both stable and convective atmospheric conditions. A comprehensive analysis of the simulated results is performed by computing the statistical performance measures for the dispersion model evaluation. The CFD model predicts 65.4% of the overall concentration points within a factor of two to the observations. It was observed that the CFD model is predicting better in convective stability conditions in comparison to the trials conducted in stable stability. In convective conditions, 74.6% points were predicted within a factor of two to the observations which are higher than 59.3% concentration points predicted within a factor of two in the trials in stable atmospheric conditions.

1. Introduction

In case of an accidental or deliberated release of the air pollutants or harmful substances into the atmosphere, it is important to predict where, when and how seriously a released contaminant can affect a specific region. In these situations, the atmospheric dispersion of hazardous contaminants is the first concern for the exposure on surrounding environment and human health, emergency response and risk assessment. The dispersion of air pollutants in the atmosphere is a challenging problem due to the complex interaction of plume with turbulent eddies and complex nature of inhomogeneous sheared turbulence near a rough boundary, meteorological and stability conditions such as wind, temperature inversion and foggy atmosphere (Kumar and Sharan, 2010). Accurate modelling of the atmospheric dispersion of pollutants is also an essential step towards developing the source reconstruction process to retrieve the location and intensity of an unknown release in a specific region (Sharan et al., 2009; Kumar et al., 2015b, etc.).

Over the years, attempts have been made for accurate modelling dispersion of pollutants released from continuous point sources in diverse atmospheric conditions using various types of the dispersion models. Several types of dispersion models, e.g., conventional Gaussian plume models (Sharan et al., 1996; Cimorelli et al., 2005, etc.), dispersion models based on the analytical solutions of simplified form of the advection-diffusion equation (Vilhena et al., 2008; Moreira et al., 2009; Kumar and Sharan, 2010, etc.), Lagrangian dispersion models (Stohl et al., 2005; Stein et al., 2015, etc.), and hybrid plume dispersion models (HPDM) (Hanna and Paine, 1989), etc. have been frequently used for short-range plume dispersion in diverse atmospheric stability conditions. With rapid advances in computer resources and methods, Computational Fluid Dynamics (CFD) models provide accurate flow fields and pollutant dispersion modelling in diverse regions for various kind of release scenarios that includes the continuous or instantaneous releases from the point, area, volume, and other general sources (Liu and Wong, 2014; Kumar et al., 2015a; Kumar and Feiz, 2016, etc.). The dispersion in the diffusion models with Computational Fluid Dynamics can be model either in Eulerian or Lagrangian particle modelling framework (Zhang and Chen, 2007). However, it is essential to examine the real predictive capability of the CFD modelling approaches to apply it in emergency contexts of an accidental or deliberate hazardous release in diverse atmospheric conditions. For this purpose, a comprehensive evaluation of the CFD model is required with the concentration

* Corresponding author.
E-mail address: pramod.kumar@univ-evry.fr (P. Kumar).

http://dx.doi.org/10.1016/j.atmosres.2017.06.025
Received 4 February 2017; Received in revised form 20 June 2017; Accepted 22 June 2017
Available online 26 June 2017

observations from a tracer field experiment in different stability conditions.

In order to evaluate the CFD simulations for pollutant dispersion in diverse atmospheric conditions, completeness and reliability of an experimental data is a necessity. Recently, a comprehensive and highly instrumented tracer field experiment called FUsing Sensor Information from Observing Networks (FUSION) Field Trial-2007 (FFT-07) was conducted in September, 2007 at Dugway Proving Ground, Utah, USA for short-range dispersion (≈ 500 m) of the pollutant released from point sources (Storwold, 2007; Platt et al., 2008). The main objective of this tracer field experiment was a comparative investigation of the Source Term Estimation (STE) methodologies in different atmospheric and release scenarios (Platt et al., 2008). The problem of the STE has attracted attention for fast and accurate identification of the unknown accidental or deliberated releases from a finite set of the atmospheric concentration measurements acquired from a deployed monitoring network (Pudykiewicz, 1998; Bocquet, 2005; Sharan et al., 2009; Kumar et al., 2015b; Kumar et al., 2016, etc.). The STE algorithms are required to use data from networked chemical and biological (CB) and other (e.g., meteorological) sensors to (1) estimate the source characteristics (source location and magnitude), and (2) refine dispersion model predictions of downwind hazards (Storwold, 2007). The FFT-07 experiment was designed to fill a key STE validation data gap, the lack of high spatial and temporal resolution dispersion measurements for single and simultaneous multiple source releases. The FFT-07 tracer field experiment includes an extensive set of the meteorological, turbulence, and concentration measurements from single, multiple, continuous and instantaneous point releases in diverse atmospheric conditions. Recently, Singh and Sharan (2013) and Pandey and Sharan (2015) evaluated a Gaussian plume dispersion model respectively for single and multiple releases trials of the FFT-07 experiment in which multiple release refers to several releases at the same time from different positions. The FFT-07 dataset completeness and high quality make the experiment an exceptional candidate for the assessment of a CFD model for near-field plume dispersion in different atmospheric stability conditions. The FFT-07 experiment is required to validate, under real-world atmospheric conditions, for forward atmospheric dispersion and the STE algorithms under development to satisfy the requirements for source characterization and hazard prediction refinement.

In this study, a CFD model fluidyn-PANACHE is evaluated with the several available trials of the FFT-07 field experiment in different atmospheric conditions. The CFD model fluidyn-PANACHE is a self-contained fully 3-dimensional (3-D) fluid dynamics, commercial CFD code, designed to simulate accidental and industrial pollutant dispersion in diverse terrains, atmospheric and release scenarios. Three-dimensional numerical simulations for each selected FFT-07 trial were performed for near-field plume dispersion from a single point continuous release using the fluidyn-PANACHE. The dispersion characteristics of the released plume from the CFD simulations are analyzed both qualitatively and quantitatively following the various statistical performance measures for air dispersion model evaluation.

2. Fusion Field Trial 2007 (FFT-07) field experiment

In this study, we utilized a recently conducted short range (≈ 500 m) comprehensive tracer field experiment at the U.S. Army's Dugway Proving Ground (DPG), Utah in September, 2007 (Storwold, 2007; Platt et al., 2008). This highly instrumented tracer experiment is referred to as FUsing Sensor Information from Observing Networks (FUSION) Field Trial 2007 (FFT-07). Most of the existing dispersion datasets measured dosages (time-integrated concentrations), which makes it impossible to replicate the instantaneous concentrations that would have challenged Chemical and Biological (CB) detectors. Only those existing dispersion datasets with high temporal resolution (1 to 50 Hz sampling rate) concentration measurements can be used with signal processing to simulate the responses of current and future CB detectors to real-world challenges. Consequently, the conceptual design for the FFT-07 was to fill the gaps in the real world data needed to validate current and future STE algorithms (Storwold, 2007). The STE methodologies developed or validated using the FFT-07 dataset can be a step towards to utilize/improve these techniques to estimate the sources in urban or other geometrically complex regions. The FFT-07 experiment provides high spatial and temporal resolution dispersion and meteorological measurements. It includes the concentration observations from various instantaneous, continuous, single as well as multiple point releases in various atmospheric stability conditions varying from neutral to stable, and unstable conditions.

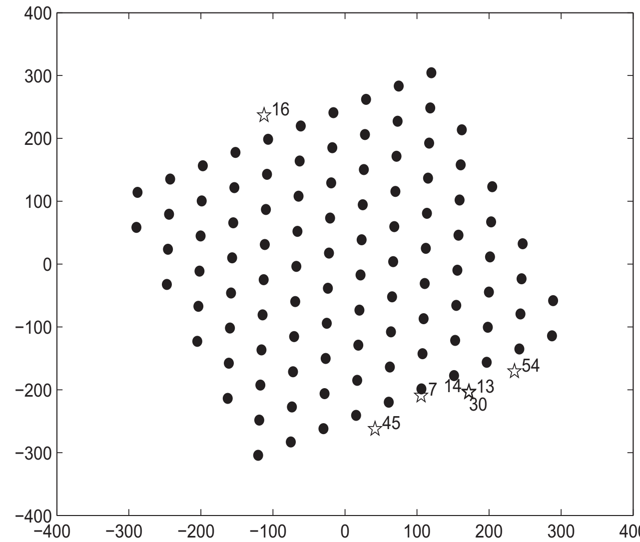

Fig. 1. Schematic layout of the FFT-07 geometry showing 100 sensor locations. The black filled circles denote the position of receptors. The stars denote the source locations of the selected trials - only one was operational in a given trial.

The design concept of the FFT-07 was to collect data from an abundance of research-grade tracer, sensor, and meteorological instruments rather than employing an “optimal” placement strategy (Storwold, 2007). In this experiment, propylene (C_3H_6) was released at 2 m height above the ground surface and the concentrations were measured at 100 fast response digital Photo Ionization Detector (digiPID) sensors deployed in a rectangular staggered grid of area 475 m × 450 m in 10 rows and 10 columns (Fig. 1). The digiPID samplers were deployed at 2 m height above the ground surface and the position of tracer source was altered according to the ambient wind direction in each trial. The terrain of the experimental site was uniform and homogeneous consisting primarily of short grass interspersed with low shrubs with a height between about 0.25 m and 0.75 m with the momentum roughness length, z_0 = 0.013 ± 0.002 m (Yee, 2012).

Extensive meteorological and turbulence measurements from many Portable Weather Instrumentation Data system (PWIDs) and ultrasonic anemometer/thermometer (sonic) and other instruments were acquired during this experiment. Three-dimensional sonic anemometers were mounted at five levels (2, 4, 8, 16, and 32 m) on three towers located at grid centre, 750 m north-northwest of grid centre, and 750 m south-southwest of grid centre. The sonic data from these three towers is processed to produce wind and turbulence statistics and surface fluxes of heat and momentum. In this study, the observations from seven FFT-07 trials 07, 13, 14, 16, 30, 45 and 45 in different atmospheric stability conditions are considered and utilized for the forward dispersion of tracer from a single point release. The atmospheric stability in each selected FFT-07 trial was categorized based on the sign of the Obukhov length (L) computed by the eddy covariance method from the sonic data measured at 4 m level of the centre tower. Other meteorological variables, e.g., wind speed, directions, and ambient air temperature, etc. are