P1.4 VORTICITY DYNAMICS OF BUOYANT PLUMES IN CROSSFLOWS

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1. INTRODUCTION

Buoyant plumes affected by crossflows have been studied extensively for several decades [see Turner (1973) for a summary of early work, and Hunt (1994) for a more recent review]. The majority of previous work in this regard is directed towards the prediction of plume rise and describes the so-called "integral models", in which profiles (typically Gaussian) of physical quantities are assumed, along with simple laws describing entrainment of ambient air into the plume.

Integral models have been shown to be successful in predicting plume rise from a variety of industrial and environmental sources, and are employed in numerous models for air quality assessment (e.g., Briggs 1975). Nevertheless, these models are frequently inadequate to describe the behavior of plumes originating from intense heat sources such as industrial or wildland fires. In such cases, the dynamics of the flow field generated by the heat source must be taken into account, since the interaction between the buoyancy-generated vorticity and the vorticity in the crossflow may be significant.

Herein, we explore the dynamics of these interactions via numerical simulations of intense heat sources in a simple crossflow with vertical shear. Two types of plume are considered:

(i) an initially two-dimensional plume arising from a line heat source; and
(ii) a three-dimensional plume arising from an isolated, axisymmetric heat sources.

In the following section, the numerical model employed is described briefly, and results are shown in section 3.

2. NUMERICAL MODEL

To adequately represent the dynamics of buoyant plumes arising from intense heat sources, it is necessary to employ the governing equations for compressible flow; to this end, we use the dynamical core of the Weather Research and Forecasting (WRF) Model (Michalakes et al. 2001).

The domain is a rectangular box with a uniform grid spacing of 8 m in all three spatial directions. The domain size is 800x400x600 m in the case of the line source, and 960x480x640 m in the case of the axisymmetric source. Boundary conditions in the streamwise (*x*) direction are open-radiative, and in the spanwise (*y*) direction are periodic in the case of the line source and open-radiative in the case of the axisymmetric source. A 5th-order upstream differencing scheme is used for both horizontal and vertical advection, and subgrid-scale turbulence is incorporated through a 1.5-order closure scheme using a prognostic equation for turbulent kinetic energy. Surface stress is imposed via a bulk drag law at the bottom boundary, while a stress-free rigid lid with a damping layer is employed at the top boundary. The basic-state stratification is neutral.

The heat source is imposed in terms of a constant rate of heat release per unit volume; this heat source has a Gaussian distribution in the horizontal direction and decays exponentially away from the surface. The heat release rate is constant in time after a brief (30 s) ramp-up period from zero. The total heat release rate is approximately 250 MW in both cases.

The crossflow is specified as an initially laminar flow in the streamwise direction as follows:

$$\bar{u}(z) = U_0 \tanh(z / z_0),$$

where $U_0 = 4\,\mathrm{m\,s^{-1}}$ and $z_0 = 75\,\mathrm{m}$.

3. RESULTS

Isosurfaces of constant potential temperature are shown in Figs. 1 and 2 for several times in the line source and axisymmetric source simulations, respectively.

It is apparent from Fig. 1 that the plume in the case of the line source exhibits an instability in the spanwise direction. This instability results in the transition of the plume from its initial two-dimensional structure to a three-dimensional one, particularly in the region far from the heat source. The vorticity field (not shown) indicates that initially the dominant vortical structure is the spanwise vortex tube associated with the plume cap, while

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at later times streamwise vortex tubes become dominant.

Figure 2 illustrates that the plume above the axisymmetric heat source bifurcates into two distinct cores. This plume bifurcation is seen frequently in association with smoke plumes above intense industrial and wildland fires and is indicative of an embedded counter-rotating vortex pair.

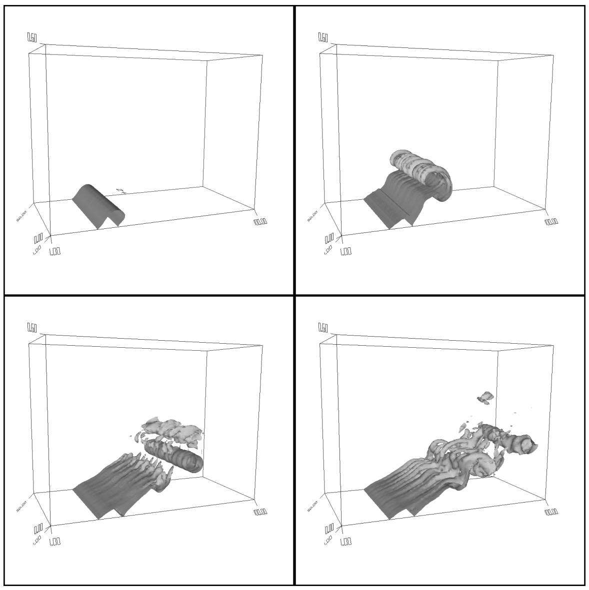

Figure 1. The 305 K isosurface of potential temperature at (a) t = 60 s, (b) t = 120 s, (c) t = 180s, (d) t = 240 s for the line source simulation.

4. DISCUSSION AND FUTURE RESEARCH

Further analysis of these simulations will be presented at the conference. Specifically, the generation and evolution of the vortical structures seen in these simulations that are associated with the interaction of the plumes with the crossflow will be described for a range of the controlling parameters [i.e., intensity of the heat source and the magnitude of the shear of the crossflow]. The implications of the results of these simulations for the dynamics of plumes arising from wildland fires will also be discussed.

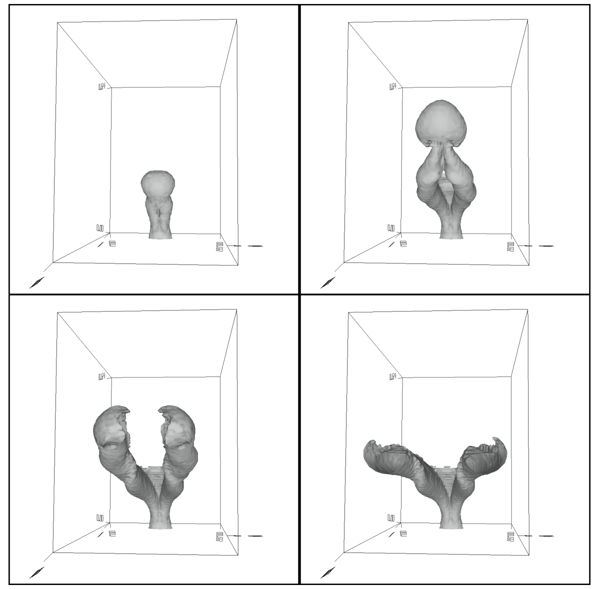

Figure 2. The 301 K isosurface of potential temperature at (a) t = 60 s, (b) t = 120 s, (c) t = 180s, (d) t = 240 s for the axisymmetric source simulation.

5. ACKNOWLEDGEMENT

This research was partially supported by the USDA Forest Service, through a cooperative agreement with the Southern Research Station.

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