A numerical study of high frequency velocity and temperature perturbations induced by a prescribed fire

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Introduction

High-frequency wind and temperature perturbations induced by prescribed or widlland fires play an important role in local-scale smoke transport and dispersion and in fire behaviors. In this study, the velocity and temperature perturbations generated by a prescribed fire are simulated using the Advanced Regional Prediction System (ARPS). The model results are analyzed to understand the behavior of the high frequency perturbations and their relationship to the temperature of the fire.

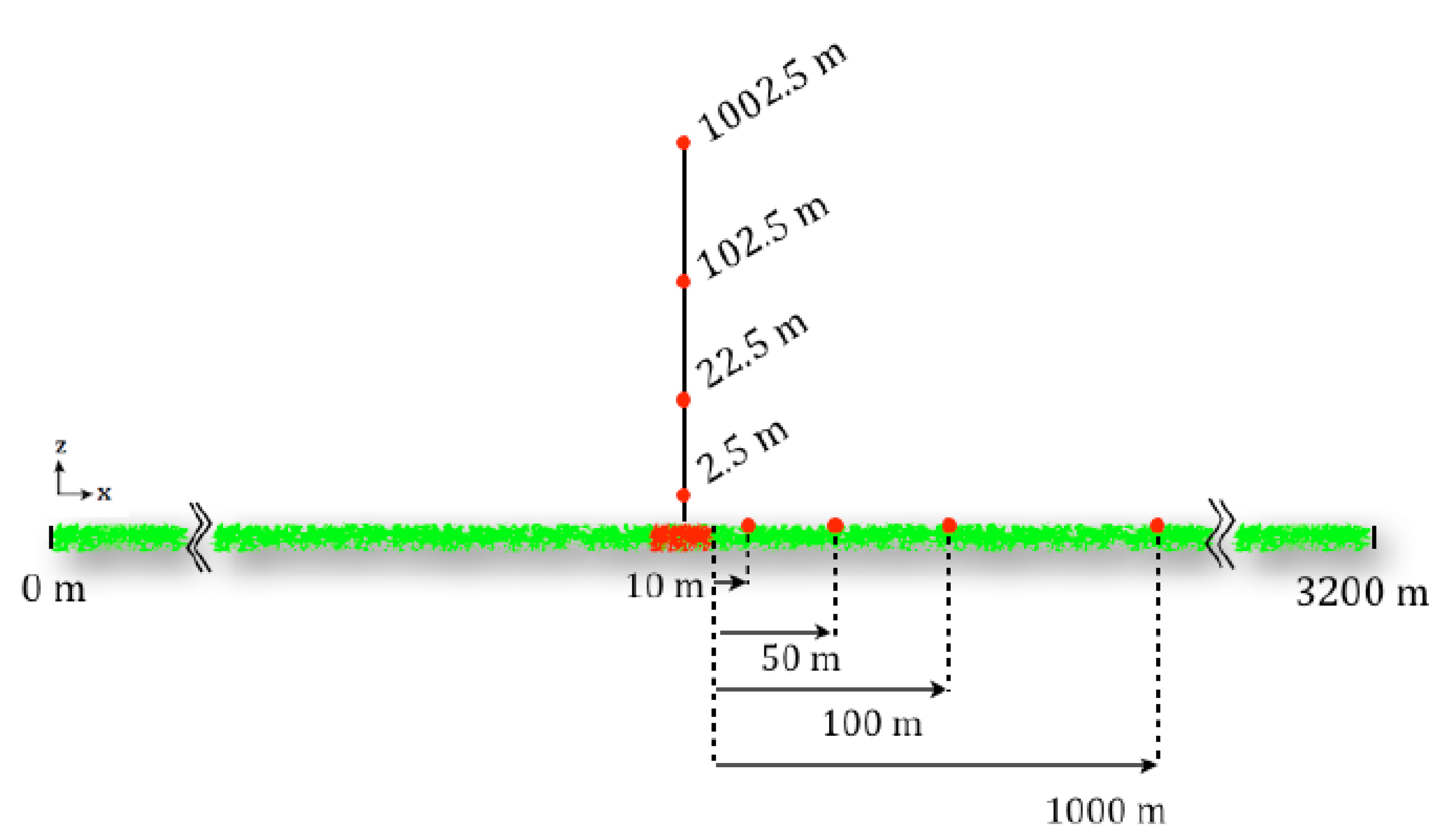


Figure 1. A schematic of the simulated domain indicating the horizontal and vertical locations (red dots) where the 1Hz velocity and temperature data was extracted from. The distances are not to scale.

Table 1. Model domain and physical parameter settings for the background simulations.

Background sim: Fire_BG_C01b	
dx	10 m
dz, min	5 m (for height < 1400 m)
nx	323
nz	300 (95% of grid points < 1400 m)
Lx	3200 km
Lz	6000 km
dt	0.1 s
BC	Periodic
Turbulence mixing	1.5 order TKE closure
Initial stability	Standard atmosphere (-6.5 C km^{-1})
Tsoil (init)	288 K
lat, long	39.88, -75.25

Model configuration

The ARPS simulations, which were performed on a 1024-CPU high performance computer (HPC), employed very-high spatial (dx = 10 m) and temporal (time step is 10-Hz or 0.1 second in integration time) resolution to explicitly resolve small-scale perturbations. Because of the extremely large demand on computer resources by the high spatial and temporal resolution simulations, the model was configured in two dimensions. Figure 1 shows the model configuration and the grid points from which the data were extracted for analysis. Table 1 summarizes the key model parameter settings.

Numerical Simulations

A convective plume was initiated by introducing a very hot surface patch with temperatures up to 1000 K. The hot surface was placed in the center of the domain along 5 grid points. This hot patch was not updated with user input temperatures, but was left as is to examine the effects of the thermal buoyancy on the nearby atmosphere. The simulations were performed for daytime unstable boundary layer (midday to 3 pm). Results from three sensitivity cases are presented here: Case-1, background or no-fire run; Case-2, fire with 500K hot patch; and Case-3, the 1000 K hot patch.

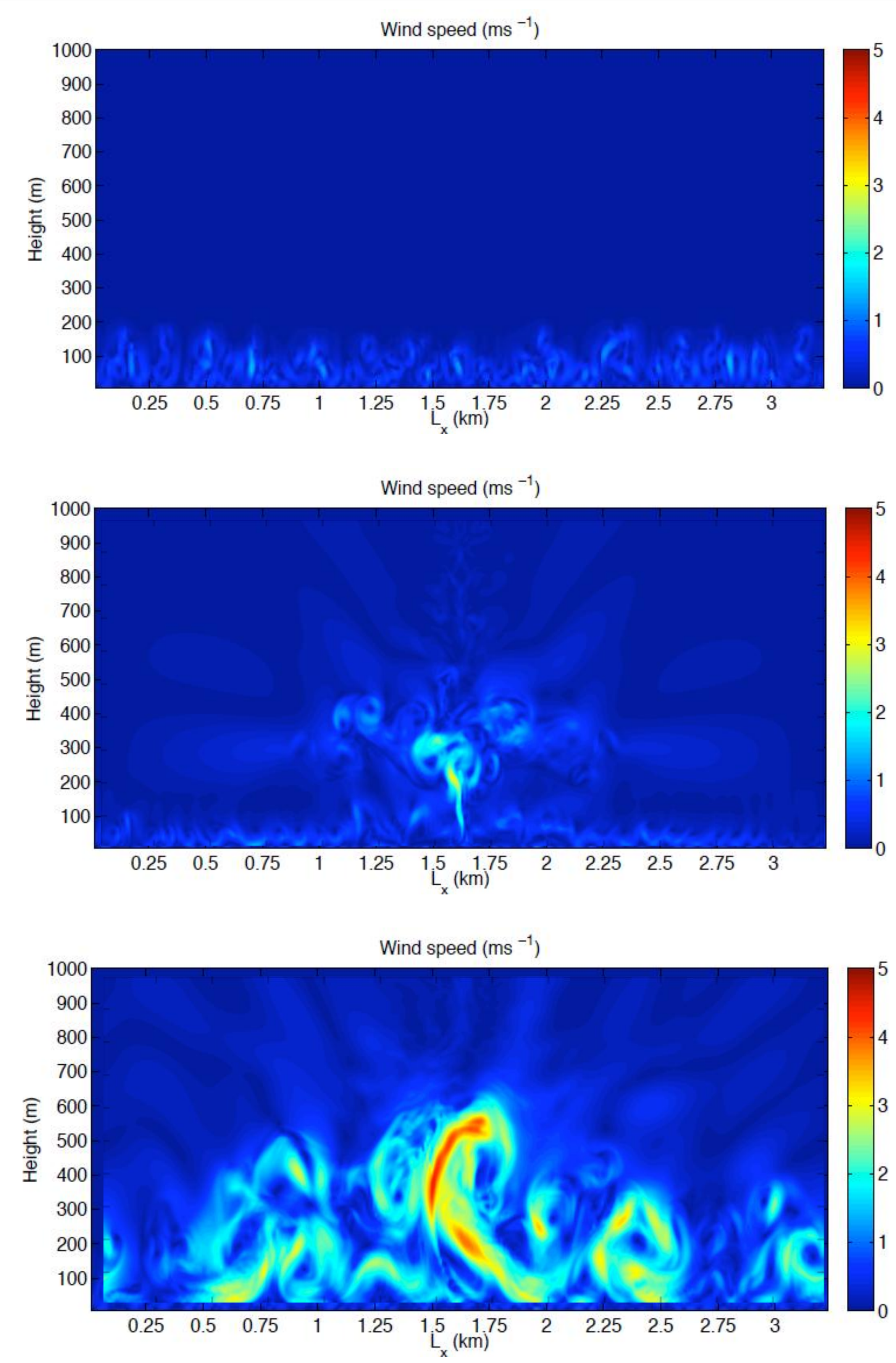


Figure 2.

(a) Case-1 No-fire (10 min into simulation)

(b) Case-3 1000 K hot patch (10 min into simulation)

(c) Case-3 1000K hot patch (60 min into simulation)

Discussion and Conclusion

The 10 Hz model output was used to compute the velocity and temperature perturbation fields and turbulence kinetic energy (TKE) associated with the convective plume.

Figure 2 shows the turbulent wind speed on a x-z cross-section. It shows 1) turbulent eddies triggered by the hot patch (comparison of top and middle plots) and 2) the increase of size and intensity of turbulent eddies as time increases after fire starts (comparison of the middle and bottom plots).

Figure 3 shows profiles of instantaneous vertical velocity for the three cases from the model domain center at hours 0, 1, 2 and 3 into the simulations. Without fire, the vertical velocity perturbation is limited to mostly below 1000 m, with small values above. With hot patches, the velocity perturbation extends to much higher level and the higher the temperature of the hot patch, the higher the vertical extension is. However, the vertical distribution patterns (up and downdrafts) and the magnitudes of the perturbation between 500 and 1000 K patches are similar.

Figure 4 shows the distribution of power density of the turbulent velocity. This figure is clearly showing an increase in the contribution of higher frequency perturbation to power density as the temperature of the hot patch raised from 500K to1000K.

A future study is planned to extend the idealized 2-D simulations to a 3-D real case simulation.

Figure 3. vertical velocity profiles

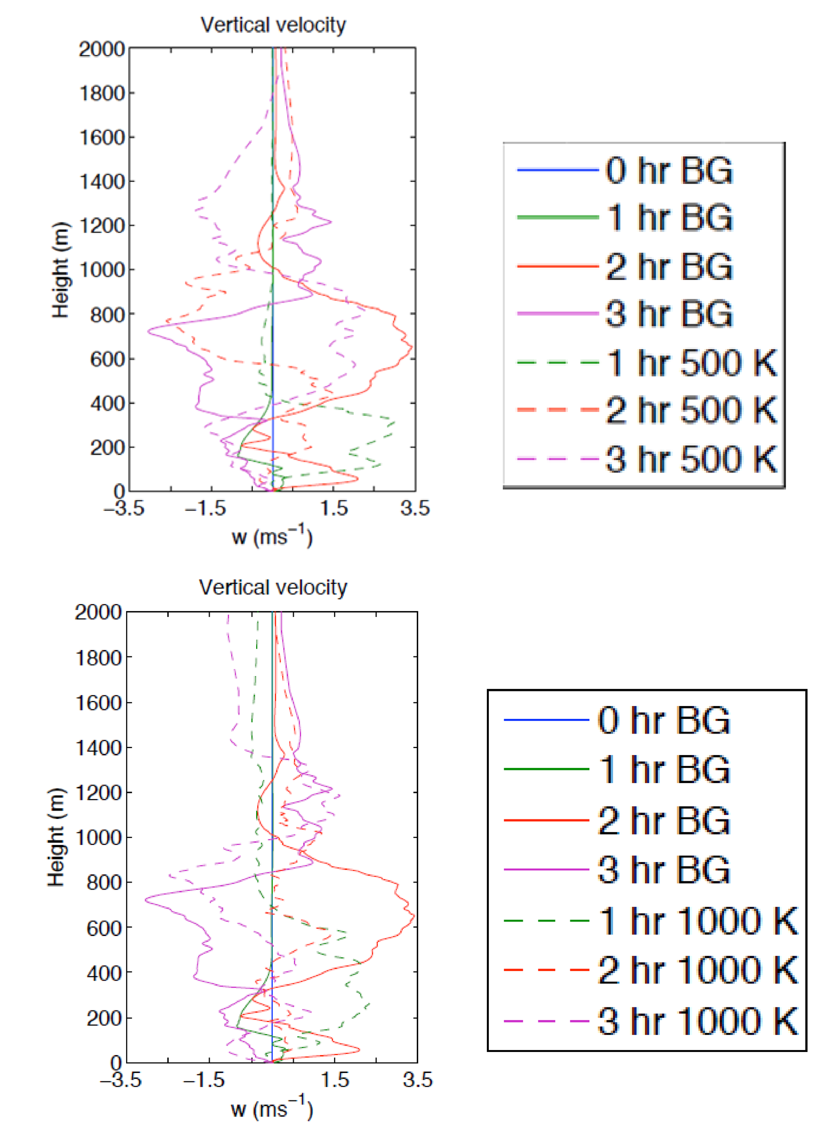
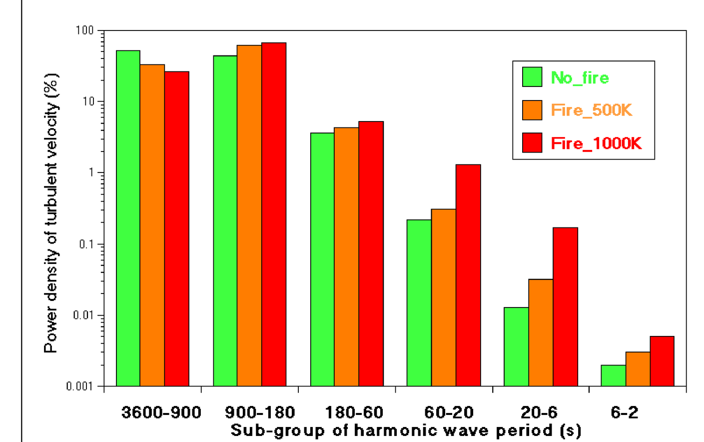


Figure 4. Power density of TKE



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