The Role Of Airborne Moments In The Spread Of The Coronavirus And The Course Of The Pandemic

Kiran Bhaganagar (kiran.bhaganagar@utsa.edu)
University of Texas, San Antonio
Sudheer BhimiReddy
University of Texas, San Antonio

Keywords: Corona Virus spread, Outdoor cough virus spread, cough plume

Posted Date: May 29th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-31166/v1

Version of Record: A version of this preprint was published on September 17th, 2020. See the published version at https://doi.org/10.1016/j.envres.2020.110170.

Scientific Reports: The Role Of Airborne Moments In The Spread Of The Coronavirus And The Course Of The Pandemic

Authors: Kiran Bhaganagar[1]* and Sudheer BhimiReddy

[1]Associate Professor and AIAA Associate Fellow, Co-lead of NASA center for Advanced Measurements in Extreme Environments, Department of Mechanical Engineering, University of Texas, San Antonio, Texas, 78248, Email: kiran.bhaganagar@utsa.edu

Abstract: A numerical study using Weather Research Forecast model and Lagrangian HYSPLIT dispersion model was conducted to understand the meteorological factors influencing the transport and mixing of the blob of Corona virus-filled micro-particles (of radius 0.12μm) released into the atmosphere due to coughing, sneezing by infected patient. The study is offered as an important contribution demonstrating the role of local atmospheric dynamics in coronavirus spread during the period of March 9 – April 6, 2020 in New York City, the epicenter of the coronavirus in the USA. The results demonstrate that from the initial time of release, the virus can spread up to 30 minutes in air, covering a 200-m radius at a time, moving 1 – 2 km from the original source. Turbulence energy containing large-scale horizontal "rolls" and vertical thermal "updrafts" and "downdrafts" contribute to transport and advection processes, before small-scale turbulent eddies rapidly mix and dilute virus concentration.

Introduction

Transport of pollutant particles in the atmosphere due to turbulence dispersion is significantly higher than molecular dispersion resulting from fluid viscosity; in addition, the local meteorology dictates the trajectory and extent of a pollutant's mixing in the atmosphere [1-2]. The cough/sneeze expectorant of a coronavirus-infected person releases respiratory droplets that contain infectious particles. Research over the past decade has indicated that a person infected with respiratory disease, such as influenza, releases a cough-jet with a significantly higher number of particles. Previous works have demonstrated that the average number of particles expelled by each cough for an infected patient can range from 900 to 302,200 [3]. Furthermore, cough particles have a wide range of sizes, with different transport characteristics. Ongoing research on coronavirus has suggested that the cough-jet of a corona-infected patient could consist of aerosols, small particles suspended in air; these particles can survive in the air for several hours [4]. Another related study demonstrated that expectorants produce turbulent clouds of gas containing clusters of droplets that propel respiratory particles forward [5]. In fact, under optimal conditions, the droplets can travel up to 7-8 m indoors, which raises an important unanswered question: How far can the blob of infected particles travel and how fast can it spread in outdoor spaces? This question will provide insights into a possible pathway for community transmission of the disease. Existing research clearly indicates the local air conditions, such as air circulation patterns, air temperature, and humidity, dictate the aerosol/blob of particles transported in the atmosphere. Turbulence is the most efficient mixing agent; the infected-blob released into surrounding turbulent air currents is transported by turbulence, entraining ambient air and becoming diluted. Atmospheric turbulence could transport the infection much faster and farther than would be possible in indoor conditions.

The virus needs moisture to survive, so the moisture content on the ground plays an additional role in allowing the virus to be active. Further, based on a recent study [4], COVID-19 can live up to 4 days depending on the surface; the life span on cardboard is 24 hours, on plastic 2-3 days, and on glass 4 days. It is very likely that the virus has a similar timeframe for survival on the ground. Overall, the transport of the infected micro-particles by air currents, the air-borne transmission of the disease, may represent an important pathway for pandemic spread. Little is known about the distance an infected patient's cloud can travel. As such, the present study seeks to use a high-resolution numerical model to obtain accurate air patterns in the New York region during the peak time period of COVID-19 in order to understand the transport processes influencing disease spread.

Turbulence is generated in the planetary boundary layer (PBL), the layer formed over the surface of the earth, due to the interactions of the surface heat and moisture flux. This turbulence influences the dispersion and transport of buoyant particle clouds released near the ground. Turbulence in the PBL is organized into accelerating air parcels (updrafts) and slower moving air parcels (downdrafts) that extend throughout the depths of the PBL when the PBL is in a convective regime [6]. The particles released by an individual are carried by these updrafts and downdrafts, and the extent and direction of dispersion depends on the PBL dynamics. Further, under the influence of the wind shear of the three-dimensional wind vector, the buoyant cloud of particles expands in size as it entrains the surrounding area pockets and eventually becomes diluted. The distance traveled by the pollutant from the initial release point and the area covered from release to dilution depends on local PBL dynamics, such as turbulent advection processes, turbulent kinetic energy, and wind shear [1]. Large-scale energy containing turbulent eddies – coherent structures – are generally the size of the PBL's depth; they advect the pollutant through turbulent advection processes, and the smaller eddies mix them with the local atmosphere.

COVID-19 is an unprecedented global pandemic that originated in Wuhan, China in late December before spreading at a very rapid rate [7-8]. In different geographical regions, the pandemic appears to be spreading at varying rates. COVID-19 clearly spreads more easily than other respiratory diseases (e.g., SARS Severe Acute Respiratory Syndrome). Micro-scaled virus particles that drift in the air or land on surfaces have multiplied into a global pandemic. Air motions transport the micro-particles, with the extent of horizontal and vertical transport of the virus cloud depending on the wind conditions at that moment in time and at that location. The virus can reach the ground and potentially spread to someone passing through that region during the lifespan of the virus. On the other hand, if transported vertically away from the ground, it disperses and loses its affinity to affect healthy individuals.

This study investigated the theory that buoyant blobs with coronavirus-filled particles (referred to as blob for the rest of the manuscript) released by infected patients' coughs are transported by turbulence processes before mixing and diluting into the atmosphere. The length- and time scales of horizontal transport are analyzed using high-resolution simulations to understand the meteorological factors influencing the transport and mixing processes. The study conducts Weather Research Forecast model simulations from March 9th to April 6th, 2020, in the New York City region to obtain meteorological details during that time. A Lagrangian model assists in simulating the transport of clusters of spherical, buoyant particles of size 0.125 microns with a half-life period of five days to quantify the transport of the infected blob subject to realistic atmospheric conditions at that location in real-time.

Methodology

We used high-resolution WRF-ARW v4.1 (Advanced Research Version of the Weather Research Forecast Model) with realistic boundary conditions to simulate detailed atmospheric conditions in the region. The model was configured with three nested domains, as shown in Fig. 1. The model WRF to simulate PBL at scales similar to this study was previously tested and verified [10-11]. Domains D01, D02, and D03 were nested with feedback turned ‘on’ with horizontal resolutions 36 km (D01), 12 km (D02), and 3 km (D03). The model top was considered at 50hPa with a total of 45 levels and 12 levels inside the PBL. The first grid point is at 24.08 m above ground. In the horizontal, D01 is discretized into a 120x120 grid, D02 into 105x105, and D03 into 103x103 grid points. The mesoscale runs were initialized at midnight 00 UTC on March 9, March 20, and April 1 of 2020 and run for a period of 7 days. Meteorological initial and boundary conditions for D01 were obtained from datasets provided by the National Centers for Environmental Predictions (NCEP) Global Forecast System Analyses (GFS-ANL), which has a horizontal resolution of 28 km; these measures were updated every 3-hrs. The GFS-ANL dataset was successful in initializing the WRF model when studying the dispersion of hazardous gas in Syria in 2017 [12]. The model output for D03 was written every 30-minutes.

The dispersion model used was the Lagrangian HYSPLIT model, which was set up with the grid center at 40.7114 N, -74.0017 W, with a concentration grid spacing of 0.0001o (~10 m) in latitude and longitudinal directions with one vertical layer from 0 to 10 m above ground level. The overall concentration grid spans 0.2o (~22 km) in latitude and longitude. The meteorological input required to run the HYSPLIT model was supplied by the WRF output from D03. To study the transport and dispersion, Lagrangian particles were released from 2 m elevation at grid center. The particle emissions rate was set to 1E7 per hour and released for 0.01 hours (~ 36 sec). The particle concentration output from HYSPLIT was measured in mass units per unit volume (mass m-3) and was collected every minute for a duration of 30 minutes from the time of release. Released particles are defined to be spherical in shape, with a diameter of 0.125 μm and density of 1.7 g cm-3. The half-life of released particles is set to 5 days. Table 1 provides the details of the cases simulated in HYSPLIT along with boundary layer height (PBLH), Monin-Obukhov length (MOL), and wind speed at 10 m at the time of release.

The concentration output from the HYSPLIT model was given on the concentration grid. A value of 1E-3 was used as the threshold, and the number of grid cells with concentration values greater than the threshold were calculated and multiplied by the grid area to give the total exposure area. Similarly, the total particle concentration at each output time-step was estimated, and the mixing ratio was calculated based on the particle density.

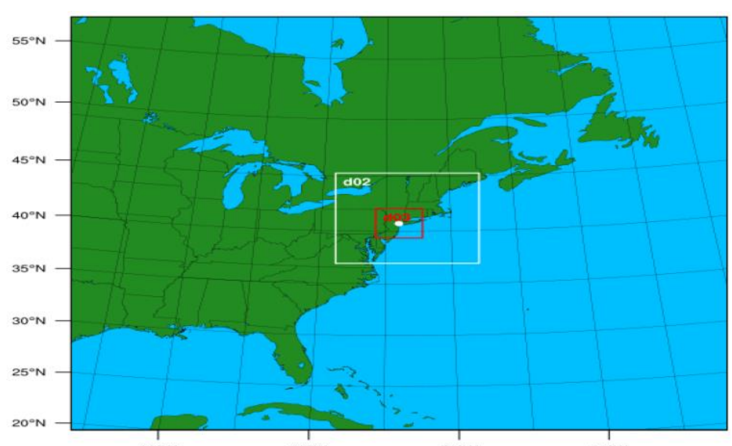

Figure 1: Numerical domain for WRF-ARW configuration over NY (white dot). The domain consists of nested grids.

Results

Trajectory of the blob subjected to realistic PBL conditions

This research analyzes the transport of virus-blobs released at different moments of time during the period of March 9th-April 6th under realistic meteorological conditions. We first investigate the transport scales of the cloud under different PBL regimes, and then analyze the role of the meteorological variables on the dynamics of transport and mixing.

Turbulence kinetic energy (TKE) is a measure of the total energy present in an air-parcel. The turbulence developed in the PBL is due to the combined effect of the heat exchange between the atmosphere and the earth's surface (buoyancy forcings) and the interaction of the wind with the earth's surface (shear forcings). The shear production of TKE from the wind shear at the surface positively contributes to the TKE production; meanwhile, the buoyancy production from the temperature gradient or heat flux at the surface can contribute positively during unstable PBL regimes and negatively during stable regimes. Based on the relative contributions from shear/buoyancy production of TKE, the governing length-scale in the PBL is the Monin-Obukhov length (L), where $L = \frac{-u_*^3 \Theta}{(\kappa\ g)(\overline{w\prime\Theta\prime})}$, κ is the Von Karman's constant, and Θ is the mean potential temperature. It is a ratio of the shear-driven processes given by the friction velocity u_* and buoyancy-generating processes given by surface heat flux ($\overline{w'\Theta'}$). Here, κ is the Von Karman's constant, and Θ is the mean potential surface temperature. Depending on the wind speeds and the relative measure of L with respect to the PBL depth z ($\zeta = z/L$), the PBL is classified into regimes, such as class A with strong convection and weak winds to class F with stable stratification and weak winds (Golder, 1972). Table 1 shows the fifteen different instances in the analysis, arranged from highly convective ζ to weakly stable stratified PBL regimes. The columns correspond to ζ, release date and time, T, z, L, wind-speed at 10 m height, wind shear close to the ground (*dU/dz*), temperature gradient close to the ground (*dT/dz*), TKE, and moisture content on the ground (amount of moisture per kg. of air).

Table 1: WRF simulations to obtain PBL characteristics

ζ=Z/L	Release (CDT)	T (K)	*z* (m)	*L* (m)	U10 (m/s)	dU/dz	TKE (m^2/s^2)	dT/dz	Q (kg/kg)
-30.78	03/11-1400	290.7	985	-32	3.1	0.02	0.66	0.05	3.5e-3
-22.16	03/22-1400	286.2	1330	-60	5.2	0.03	1.08	0.06	2.1e-3
-8.69	03/12-1400	289.8	800	-92	6.2	0.03	0.13	0.05	5.5e-3
-8.31	04/05-1400	292.7	665	-80	6.3	0.03	1.12	0.06	5.5e-3
-5.95	04/02-1400	290.6	1565	-263	10.2	0.03	2.63	0.05	3.5e-3
-5.28	04/05-0700	281.4	211	-40	1.9	0.01	0.15	0.01	5.5e-3
-3.5	04/02-0700	278.6	1022	-292	5.7	0.02	0.79	0.02	3.5e-3
-2.9	03/22-0700	274.6	749	-258	6.4	0.02	0.93	0.02	3e-3
-2.05	03/21-1900	280.1	1114	-542	5.3	0.01	0.61	0.006	2e-3
-1.44	03/12-0700	277.5	307	-213	2.6	0.008	0.18	0.005	4.5e-3
-1.4	03/11-0700	277.7	419	-300	4.2	0.01	0.39	0.01	3e-3
-1.39	03/11-1900	280.7	368	-265	4.4	0.01	0.45	0.008	7.5e-3

-1.25	04/04-1900	283.8	274	-220	3.5	0.0007	0.28	-0.0001	5.5e-3
0.63	04/01-1900	283.3	739	1182	5.2	0.002	0.62	-0.01	3.2e-3
2.75	03/10-1900	285.7	921	335	5.3	0.01	0.67	-0.03	7e-3

Three sets of WRF simulations were conducted in the New York City region (see Fig. 1) for the domain) during the time periods of March 9-16, March 22-26, and April 1-6 to obtain a detailed micro-climatology of the region. The virus-blob was released at different time-instants in the PBL, and the trajectory of the particles was calculated in real-time for each instance of the release using a Lagrangian model. The analysis for the release of the blob on April 2 0700 CDT is presented here. This corresponds to a PBL regime of ζ = -3.5 (Table 1). Fig. 2a-f shows the trajectory of the blob for times at t = 2 min, 5 min, 10 min, 15 min, 20 min and 29 min after release (i.e., t= 0 min). The color maps correspond to the average concentration from 0-10 meters above the ground overlaid on a geographical map of the region. The plan view shows the horizontal east-west and north-south directions. The (0,0) location is the blob's point of release corresponding to latitude and longitude of (74W, 40N), as shown by the red circle. Released as a point source at t = 0, the blob starts to move away from the point of release and also expands horizontally as it spreads. At 10 minutes following the release time, the direction of the blob is towards the north-west of the initial location, and at 15 min and beyond, it continues to move in that direction while growing in size. After 10 minutes, the blob is 2.5 km east and 1 km north of the original location, and it moves towards New Jersey at 15 minutes. At 29 minutes, it is 7 km east and 6 km north of its original location. As the blob moves, the ambient air mixes with the contaminant, diluting the blob. In this case, it takes around 30 minutes to be completely diluted.

The trajectory of the blob and the mixing can be explored using a micro-climate analysis at 0700 hours CDT on April 2nd. WRF simulations reveal that the PBL is in a moderately convective regime characterized by a deep PBL layer of 1022 m, winds at a moderate speed of 5.2 m/s, and moderate turbulence blowing over the region. There is a cool ground temperature of 278.6K with a moisture content of 3.5e-3 kg/kg of air, and the wind-shear is stronger than the thermal gradient on the ground (Table 1). The wind-shear and the positive temperature gradient at the surface act as sources of TKE production, resulting in the generation of TKE from both shear-driven and buoyancy-driven processes. The horizontal velocity vectors (*u-v)* colored with the PBL depth at release time are shown in Fig. 3a. The region is influenced by moderate winds that blow towards the ocean. Turbulence is organized as updrafts and downdrafts with a vertical velocity of around 1m/s, as seen in Fig. **3b**. The energy containing convective rolls influence the trajectory of the blob.

To understand the differences in trajectory for different release conditions, the supplemental section presents two additional sets of cases, with the release conditions of April 5 0700 hours CDT (ζ=-5.28) and March 10 1900 hours CDT (ζ=2.75). WRF simulations demonstrate that the PBL exhibits different characteristics for these regimes. For example, the PBL is in a moderately convective regime; however, it is shallow in depth with low winds and weak turbulence generated from a combination of low shear-driven and low buoyancy-driven production when ζ=-5.28. Turbulence is generated due to a small negative temperature gradient (sink of TKE production) and a positive high wind-shear (source of TKE production). Fig. 4 a-f shows the trajectory of the blob at 5 min, 10 min, 15 min, 20 min, 25 min, and 30 min after the release time. At 5 minutes, the blob expands in area; however, the transport of the blob is slow compared to the ζ=-3.5 case. The blob continues to move eastwards for a distance of 0.5 km and 2.5 km from the source, 10 minutes and 20 minutes after release, respectively. The region is influenced by stronger southwest marine winds and weaker circulation over the land of less than 5m/s, resulting in an elliptical region of coverage. Fig. 5 a-f shows the trajectory of the blob released on March 10 1900 CDT at 2 min, 5 min, 10 min, 15 min, and 20 min after release time. The PBL is deep, representing a transition from a neutral to a stable regime. At 5 minutes after release, the blob moves 1km north-east towards a densely populated area, and it continues in this direction, having moved 5 km after 20 minutes before mixing and becoming diluted 30 minutes after release. The wind patterns are extremely complicated with the convergence of strong circulations from the marine boundary layer to the south-east, winds blowing from the north in the eastern part, and north-west winds in the western area.

In summary, the response of the blob to atmospheric turbulence is dictated by PBL characteristics, such as wind shear, temperature gradient, energy containing horizontal rolls, and turbulence. Next, we analyze the area covered by the blob as it moves in time. All fifteen cases are analyzed here. Fig. 6a shows the area covered by the virus-blob in time as it expands due to the local turbulence until it dilutes due to mixing with the atmosphere. Fig. 6b shows the mixing ratio of the blob (ratio of contaminant density at a given time to the initial density in the blob). The spreading rate at which it mixes with the ambience before dilution strongly depends on the meteorological conditions. During moderately convective conditions (ζ = -5.95) in a deep boundary layer with high turbulence and strong winds, the virus-cloud expands and transports quickly, e.g., covering a region of 0.5 x10^5 m^2 (radius of 40 m) in 1 minute and 10^5 m^2 (radius of 180 m) in 3 minutes. It mixes and dilutes quickly in 25 minutes. However, if the boundary layer is shallow (ζ = -5.28) with low turbulence and gentle winds, the virus-cloud is less confined (e.g., it covers half the area of the previous state; however, it persists without diluting for a longer time). Weakly convective conditions (ζ = -1.44.-1.4.-1.39) with a shallow boundary layer and gentle winds and low turbulence results in the mixing of the virus-cloud throughout the PBL depth in the order of 200 m, causing an undiluted virus-blob to spread to a larger area for a longer amount of time. In the two cases corresponding to stable PBL regimes, ζ = 0.63, 0.75, the PBL depth is deep and the TKE production is mainly due to the wind-shear as the contribution from buoyancy-generated TKE is very low. This suggests that these regimes represent transition from a neutral to a stable regime. The conditions are characterized by low winds of around 5 m/s and moderate shear-driven turbulence. The mixing is dictated by purely shear-driven processes. The blob expands to a maximum area of 1.2/1.5 x $10^5$$m^2$ (or a radius of 200/220 m) for cases ζ = 2.65/0.73, and it persists in size for a longer time.

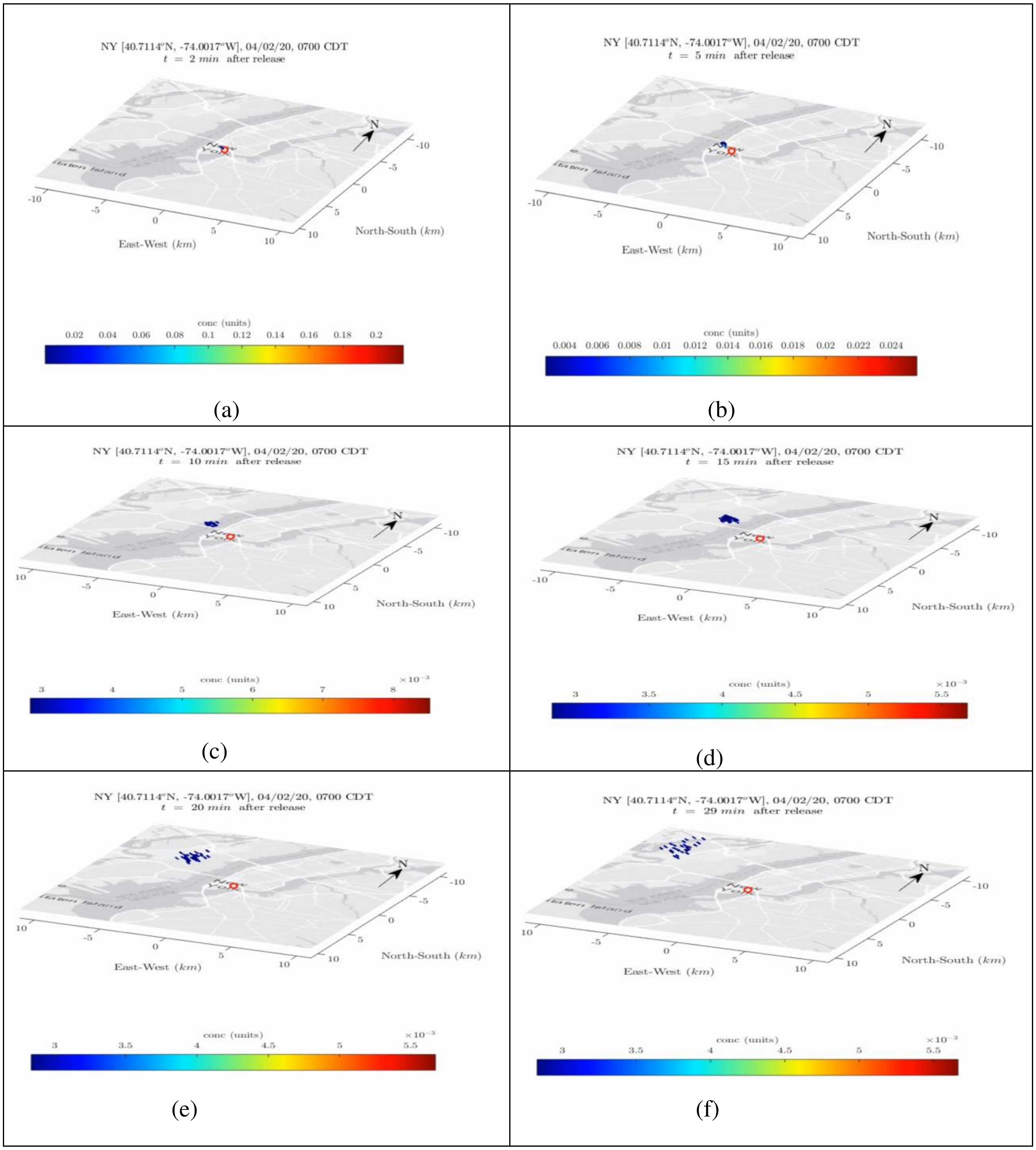

Figure 2: For the April 2nd 0700 hours CDT release, the trajectory of the blob released at time *t*= 0 along the north-south and east-west plane at (a) *t* = 2 min, (b) 5 min, (c) 10 min, (d) 15 min, (e) 20 min, (f) 29 minutes after the release time.

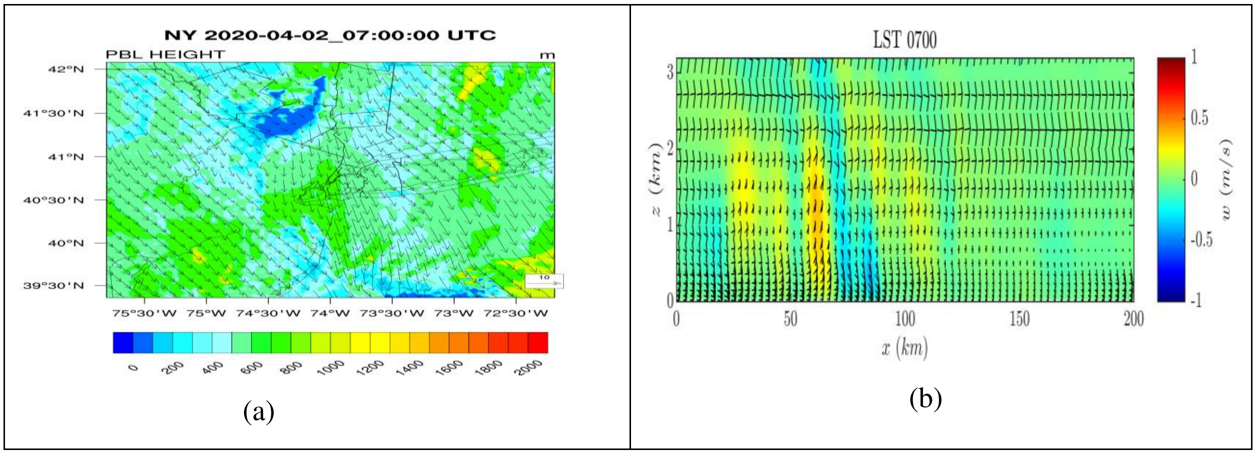

Fig 3: Wind vectors for April 2, 0700 CDT hours release (a) velocity vectors in the latitude-longitude plane colored with PBL height, (b) horizontal convective rolls in *x*-*z* plane.

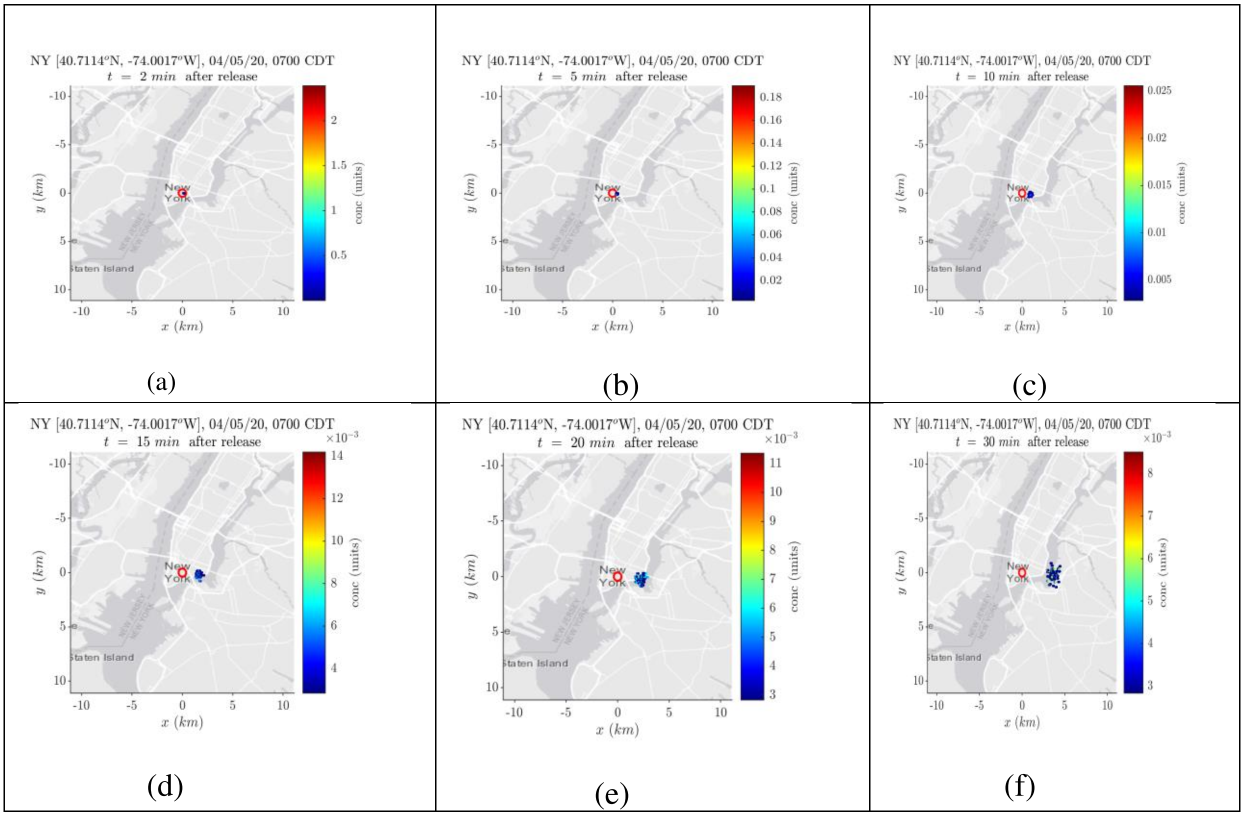

Fig 4: April 5, 0700 CDT Release (a) 2 minutes (b) 5 minutes (c) 10 minutes (d) 15 minutes (e) 20 minutes (f) 30 minutes

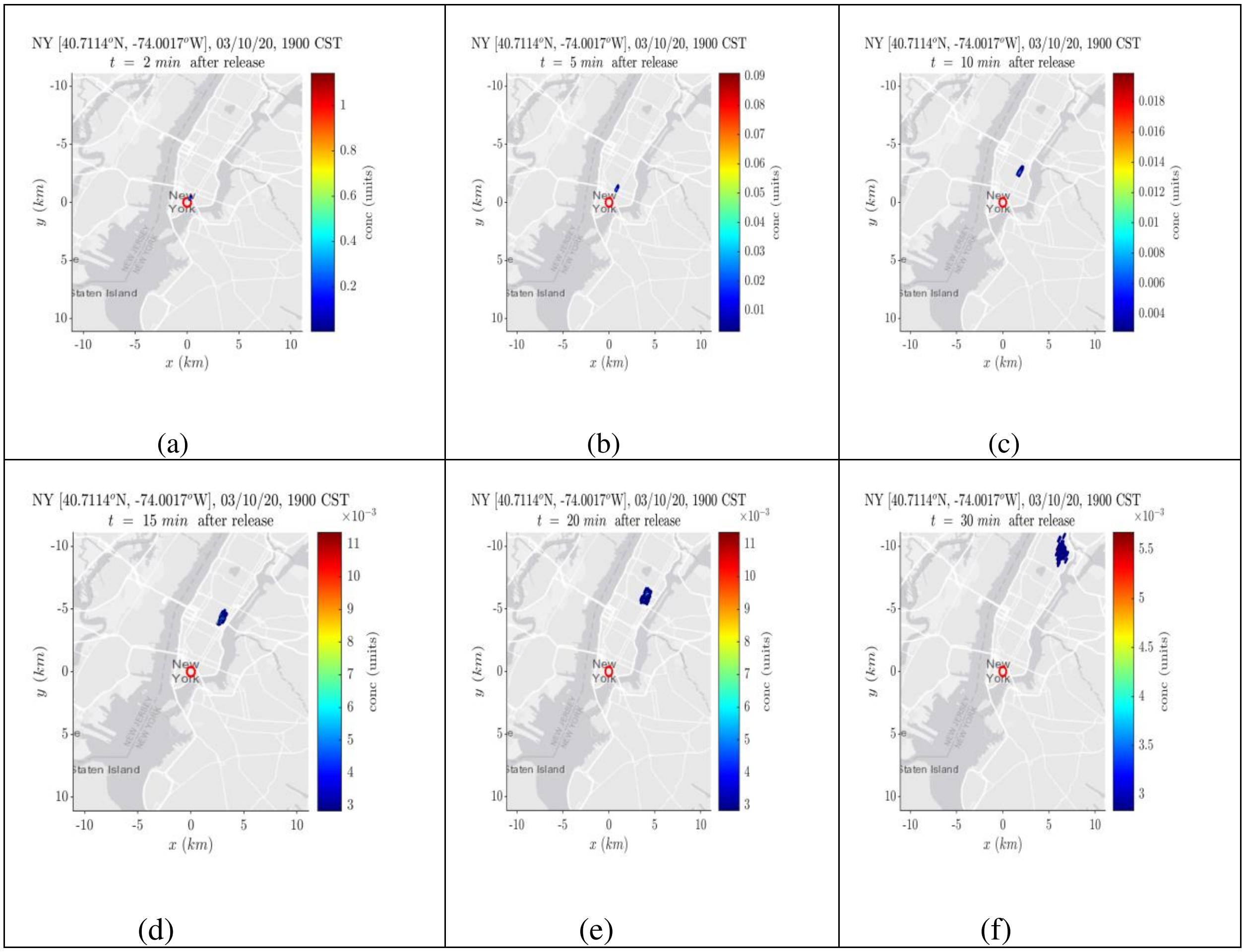

Figure 5: March 10, 1900 CDT Release (a) 2 minutes (b) 5 minutes (c) 10 minutes (d) 15 minutes (e) 20 minutes (f) 30 minutes

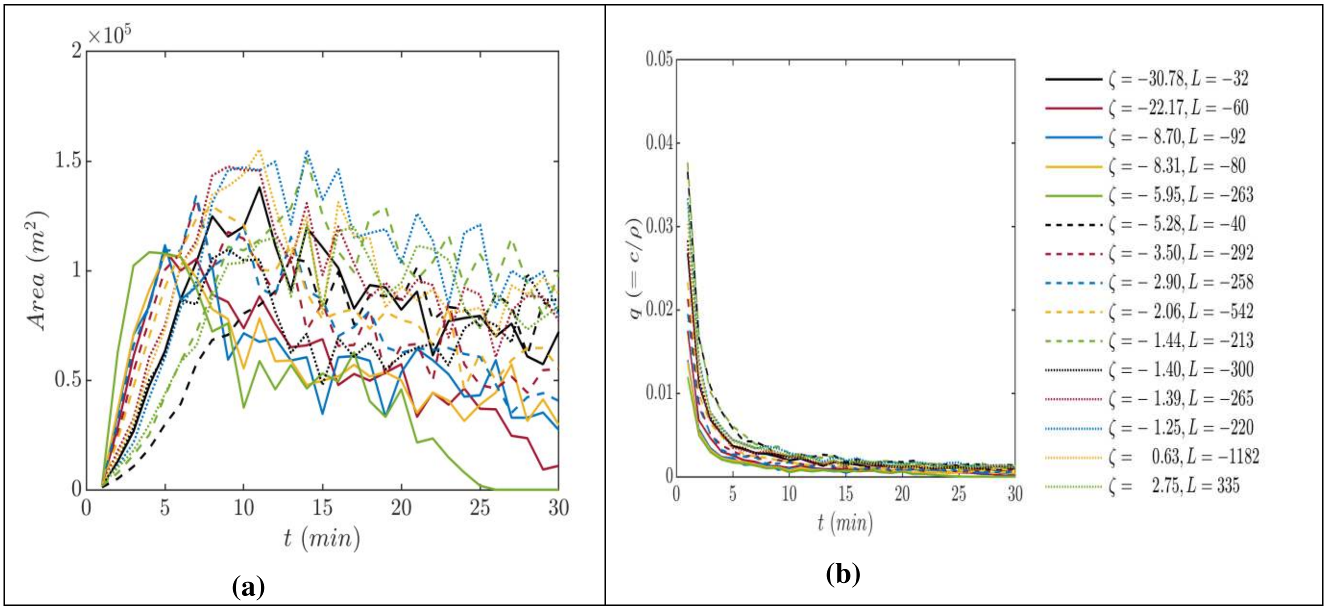

Fig 6: (a) Area covered by the virus-cloud at times (minutes) from the time of release, (b) mixing of the pollutant with the atmosphere in time (See Table 1).

Variations in the atmospheric stability and local climate of the New York region

The urban boundary layer in New York City is influenced greatly by the sea breeze due to the ocean's proximity. We analyze the role of local meteorological variables on the direction of transport from the initial release location and the meteorological variables that influence the direction. Fig. 7 a-d shows the diurnal variations of the PBL characteristics during the periods of March 9-14, March 20-26, and April 1-6. The period of March 9-14 is characterized by average winds of 5 m/s with an isolated event of peak winds at 10 m/s. Later, during the month of March and during the period of April 1-6, there exist significant inter-daily variations, including events of high winds of around 10 m/s and low winds of 2 m/s. The wind direction does not exhibit any specific trends, and there appear significant variations. The PBL depths are deep for a significant number of days during the day-time conditions, and they also are marked by shallow night-time conditions. The atmospheric stability parameter L shows strong diurnal variations as the values change from positive to negative during the heating/cooling of the surface during daytime/nighttime conditions. In summary, during the analysis period, the PBL is predominantly in a convective regime, with a few instances of purely stable regimes. Turbulence in convective regimes is organized as large-scale coherent structures, which play a dominant role in transporting the blob.

Fig. 8a shows the turbulence structures in the PBL. The PBL is characterized by well-developed horizontal rolls with strong updrafts and downdrafts. The size of the rolls (*u*-*w*) on April 4th vary; for instance, the rolls are 9 km wide and 1.5 km in height (size of each roll) at 1700, and they are 3 km wide and 1 km in height. The (*v*-*w*) rolls on April 3rd are narrower but deeper with a width of 1.5 km and extending to 1.8 km deep. As seen in Fig. 8b, the (*v*-*w*) rolls on April 3rd are narrower but deeper, with a width of 1.5 km and extending to 1.8 km deep.

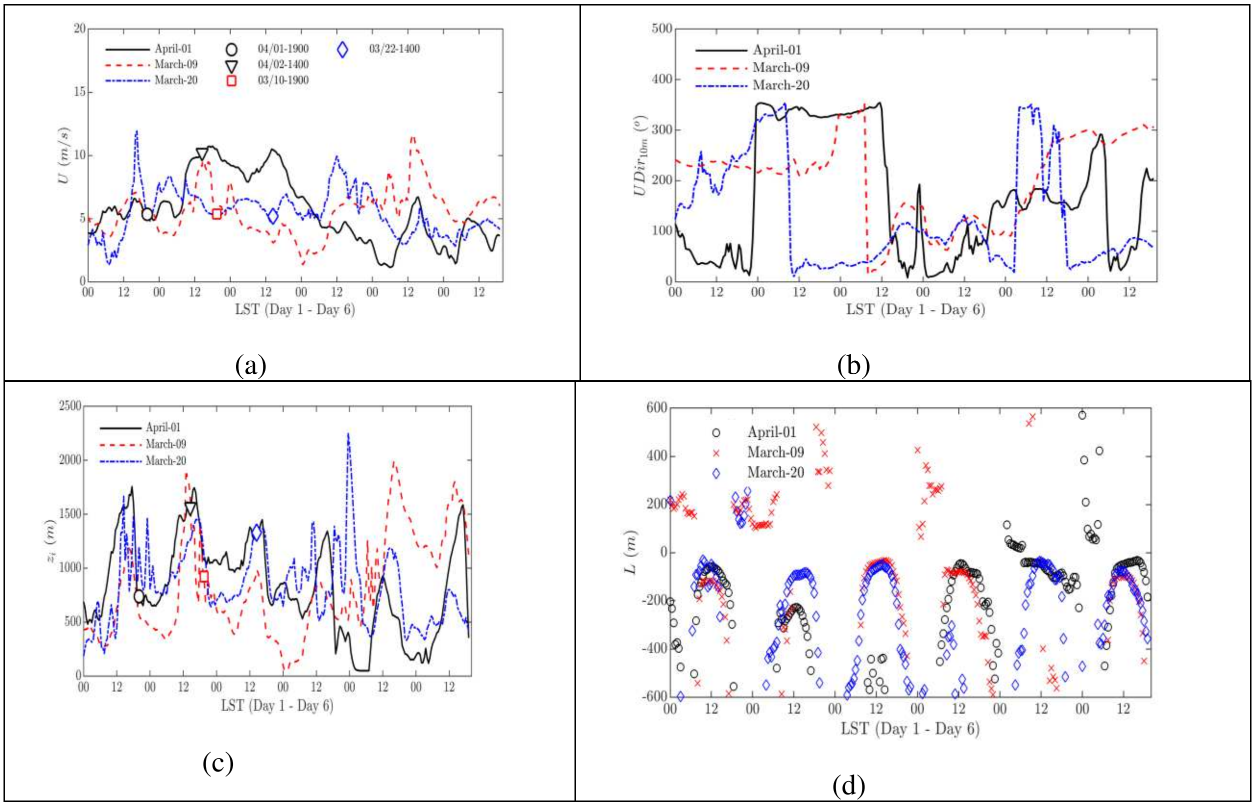

Figure 7: WRF simulation results for periods covering March 9-16, March 22- 26, April 1- 6: (a) Wind speed at 10 m height, (b) Wind direction at 10 m height, (c) PBL height, (d) Scale L

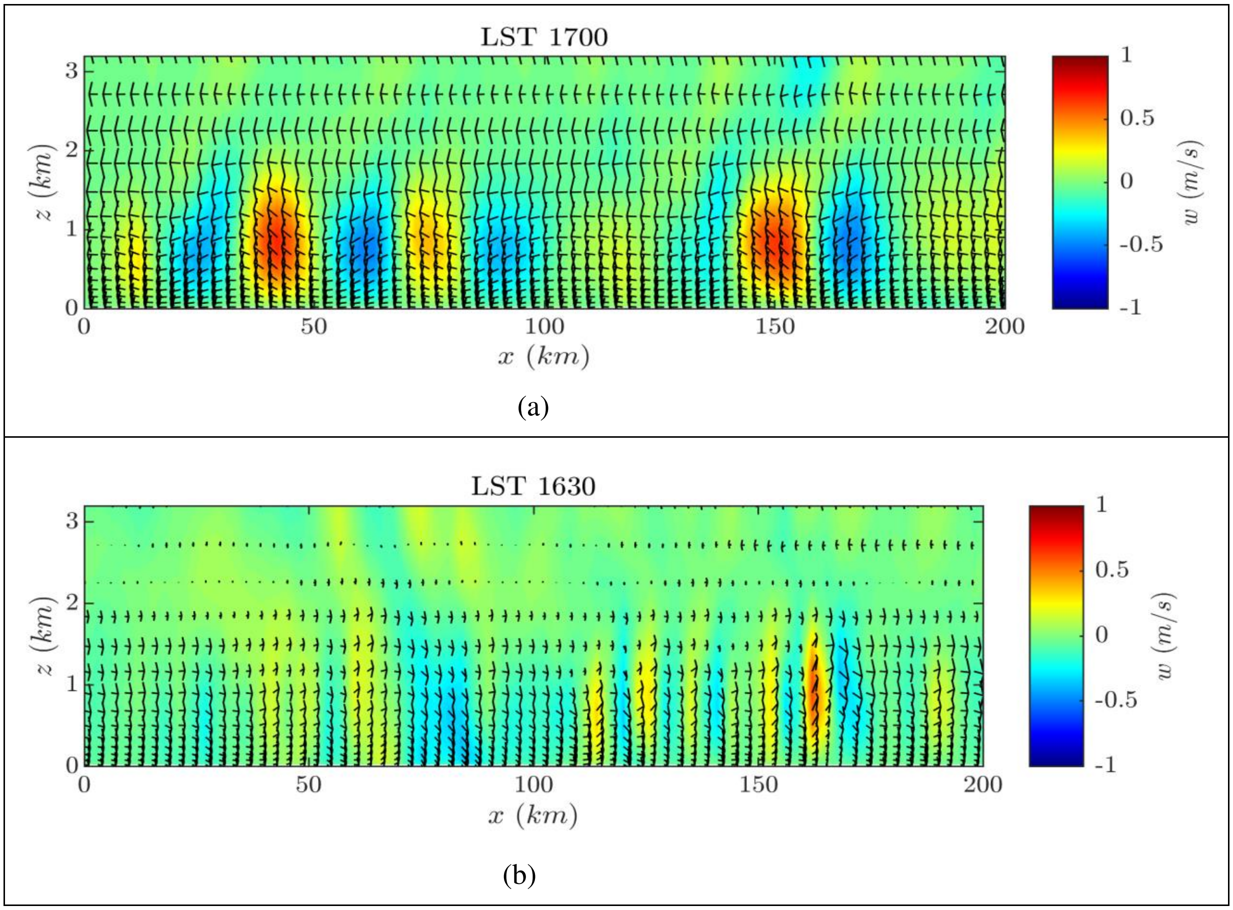

Fig 8: Horizontal roll (*u*-*v* vectors colored with *w* contours) at different time-instants of the WRF simulations: (a) April 4, 1700 hours CDT, (b) April 3, 1630 hours CDT.

Discussion

A computationally intensive study has been performed to accurately represent the dispersion processes and the factors influencing the transport and mixing of the cloud or blob of virus-filled micro-particles released due to coughing, sneezing, or similar events into the atmosphere. The motivation of the study is two-fold. First, the New York region has become the epicenter of coronavirus spread in the USA, with a steady increase in disease spread beginning in March and continuing to date. Therefore, there is an urgent need to conduct a study specific to the New York region during this period in order to gain an understanding of the key factors that correlate with the spread of the disease. Second, there is no knowledge regarding the possibility of infection spread due to coughing/sneezing and air-current conditions in the atmosphere. As such, this study provides an important direction for future research, with direct implications on social distancing protocols and face masks for protection, to name but two. The approach used in this study consists of a Lagrangian dispersion model to determine the trajectory of COVID-19 micro-particles released into the atmosphere subject to realistic atmospheric forcings and wind conditions. An advanced WRF-ARW numerical model allows the simulation of accurate meteorological conditions during the time period under analysis. The assumptions of the study are based on the existing published literature. At the initial time of the simulation, 100,000 particles (which corresponds to a rate of 2800 particles/second), spherical in shape with diameter of 0.125 μm, and a density of 1.7 g cm^{-3}, were released into the atmospheric boundary layer at a height of 2 m above the ground.

Detailed and high-resolution simulations have been performed for three periods: March 10-16, March 22-28, and April 1-6 of 2020. The domain of the simulation is the New York City region. In this region, WRF-ARM results demonstrate that the PBL is in different regimes, corresponding to weakly convective, moderately convective, and near-neutral transitioning to stable regimes based on ζ (z/L) during the periods in the simulation. Each of these regimes is further differentiated based on low/high wind speeds and low/high turbulence; for example, the regime for moderately convective with low winds and high turbulence differs from moderately convective with high winds and low turbulence. Together, the PBL regime, 3-D wind patterns, and turbulence influence how far and how long the released particles travel before they become diluted due to turbulence mixing. In weakly/moderately convective regimes, the wind-shear and buoyancy-forcings (temperature gradient on the ground) are the forcings that contribute positively to TKE generation. Turbulence is an agent that advects (in three-dimensions) and also mixes the blob of released micro-particles. Due to the three-dimensional advection processes, the original point source increases in size and also moves farther away from the release location. Turbulence mixing is very efficient, and the micro-particles mix with the surrounding air currents, eventually diluting the concentration of the infected particles per unit volume of air inhaled by individuals. Detailed analysis has been conducted to quantify the meteorological factors that influence the transport, mixing, and dilution processes.

In weakly/moderately convective regimes, the PBL contains buoyancy- and shear-induced motions that influence the transport and mixing of a blob released close to the ground (2 m height). The buoyancy-induced motions form updrafts, regions of positive vertical velocity fluctuations (away from the ground direction), and downdrafts, broad regions of negative vertical velocity fluctuations (towards the ground direction). The shear-induced motions due to the wind shear form horizontal convective "rolls" – large-scale coherent structures that align with the mean wind. When released close to the ground, the virus-blob with a particle concentration c is advected by the updrafts/downdrafts vertically (towards the ground or away from the ground) that transport the cloud before it mixes with the atmosphere and becomes diluted. The flux is carried by buoyancy-induced vertical motions when released in weakly or moderately convective PBL, whereas for $\zeta >$ 0 cases, the shear-induced motions give rise to the upward flux of the virus-cloud. The shear-driven turbulence production mixes and dilutes it.

To quantify the extent of spread of the virus blob released into the atmosphere, we determine the area (or the radius) covered by the blob and the mixing ratio, the ratio of the density of the blob with respect to the initial density of the particles. The PBL depth (shallow vs. deep), wind speeds (low, moderate, or high), and turbulence (low or high) influence the rate at which the blob spreads, mixes, and gets diluted. During the period of March 10-April 7, the analysis reveals that the higher the turbulence, the faster the mixing and dilution. Lower turbulence leads to the persistence of the blob for a longer time. In weakly and moderately convective regimes, the transport direction and the extent of blob spread correlate with the wind shear and the temperature gradient, and with the scales of the horizontal rolls and thermal updrafts and downdrafts. In neutral conditions (or stable regimes with a deep boundary layer), the transport correlates only with the wind-shear, and the buoyancy effects do not contribute. Overall, depending on the regimes of release, the blob expands to a radius of 180-200 m in the horizontal plane (latitude-longitude) within 5-15 minutes after release, and the blob is active before it dilutes and mixes with the ambience for a time period of 25-30 minutes after release. The direction of the transport in the latitude-longitude plane is mainly dictated by the meteorological conditions. For instance, during the April 2, 700 release, the blob moves in a north-west direction, and it is 7 km east and 6 km north of the source at 29 minutes before becoming diluted. During the April 5 700 CDT release, the blob moves 2.5 km east in 20 minutes before it is diluted.

The study provides robust evidence to the recent report by National Academy of Science raising concerns about transmission of SARS-COV-2 via aerosols generated from droplets [13]. The report indicated an airflow modeling study following the SARS-CoV-1 outbreak suggesting the spread of disease as a rising plume of contaminated warm air [14]. This study is offered as an important contribution demonstrating the role of local meteorological conditions in spreading the coronavirus, and the results demonstrate that, from the initial time of release, the virus can spread up to 30 minutes in air, covering a 200 m radius region at a time and moving to 1-2 km from the original source.

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Acknowledgments: The author acknowledge Texas Advanced Computing Center (TACC) for provide timely and valuable supercomputing facilities to conduct the simulations. **Funding:** The work has been funded by NASA MURI Grant; **Author contributions:** KB was involved in writing the manuscript, conducting the background study and detailed analysis of the results. SB was involved in performing the numerical model simulations and post-processing the data. **Competing interests:** Authors declare no competing interests.; and **Data and materials availability:** All data is available in the main text or the supplementary materials.

Figures

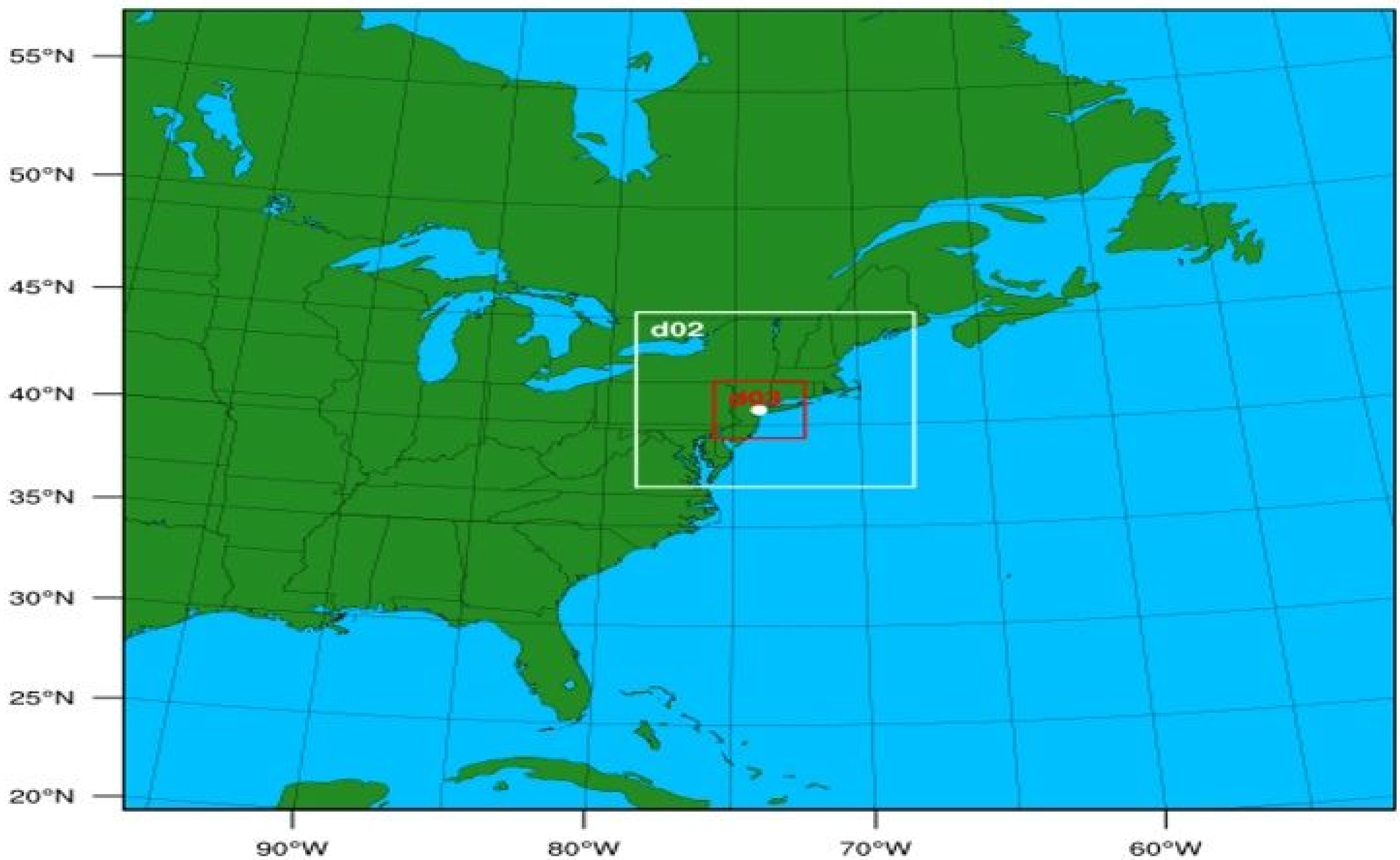

Figure 1

Numerical domain for WRF-ARW configuration over NY (white dot). The domain consists of nested grids.

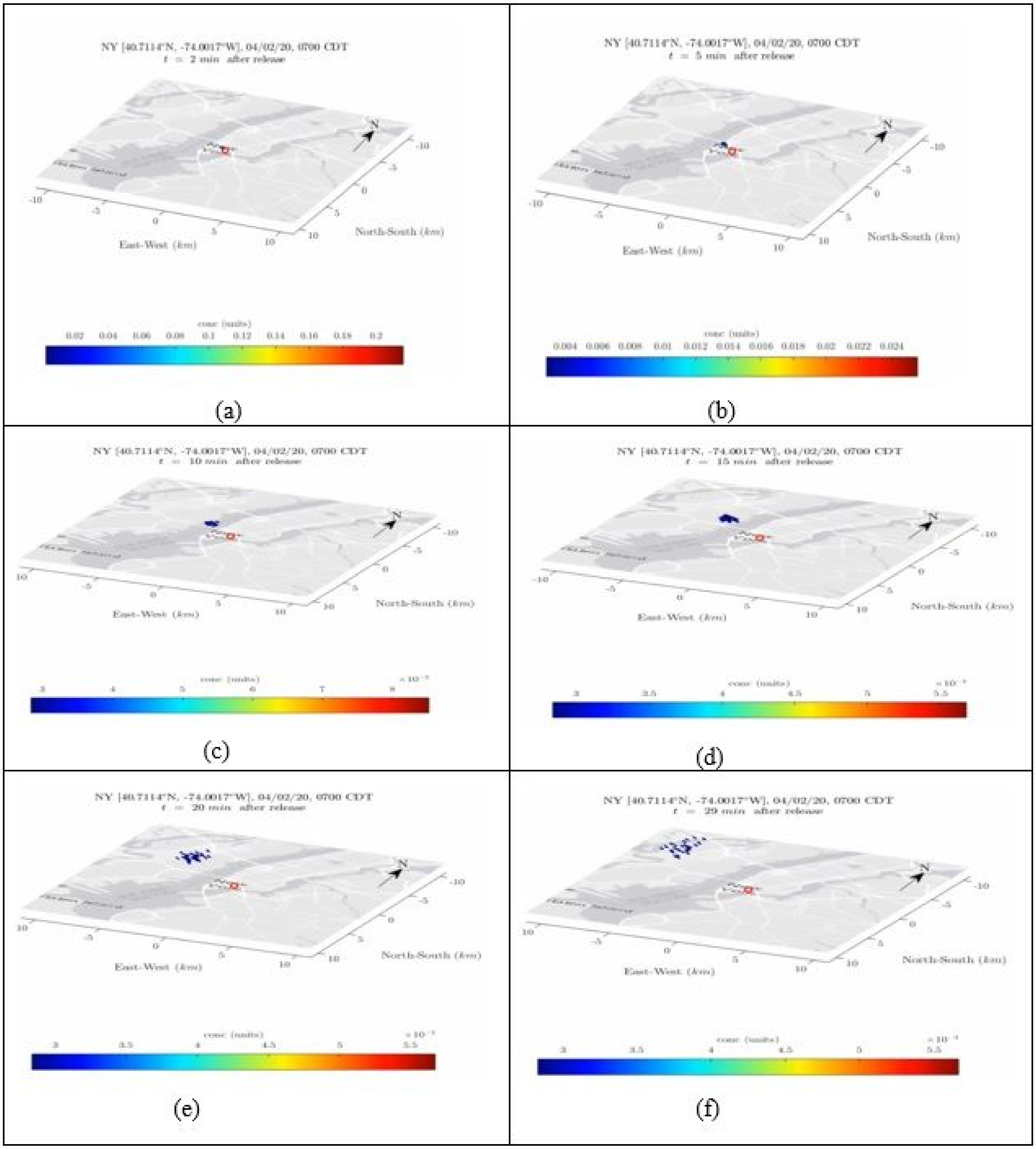

Figure 2

For the April 2nd 0700 hours CDT release, the trajectory of the blob released at time t= 0 along the north-south and east-west plane at (a) t = 2 min, (b) 5 min, (c) 10 min, (d) 15 min, (e) 20 min, (f) 29 minutes after the release time.

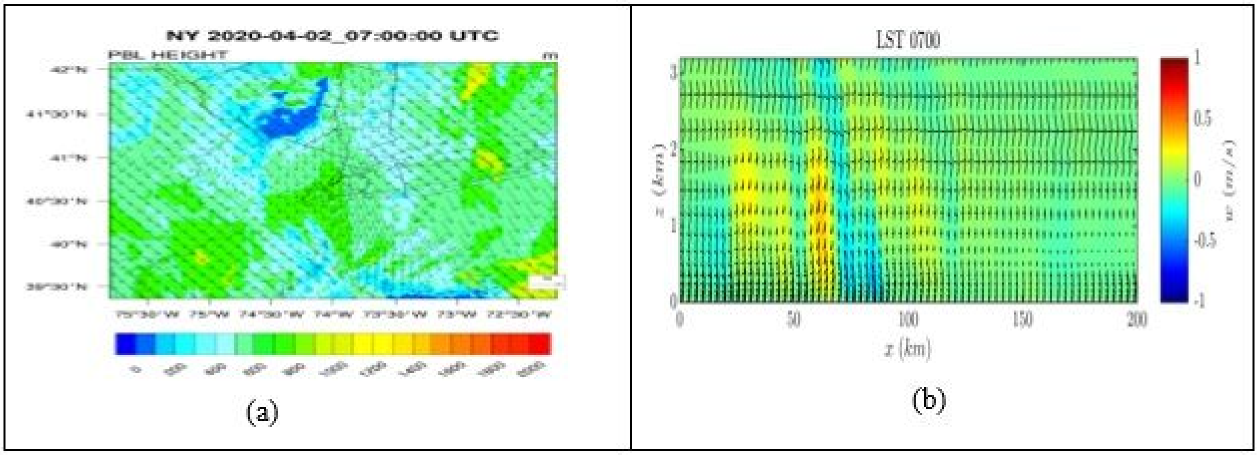

Figure 3

Wind vectors for April 2, 0700 CDT hours release (a) velocity vectors in the latitude-longitude plane colored with PBL height, (b) horizontal convective rolls in x-z plane.

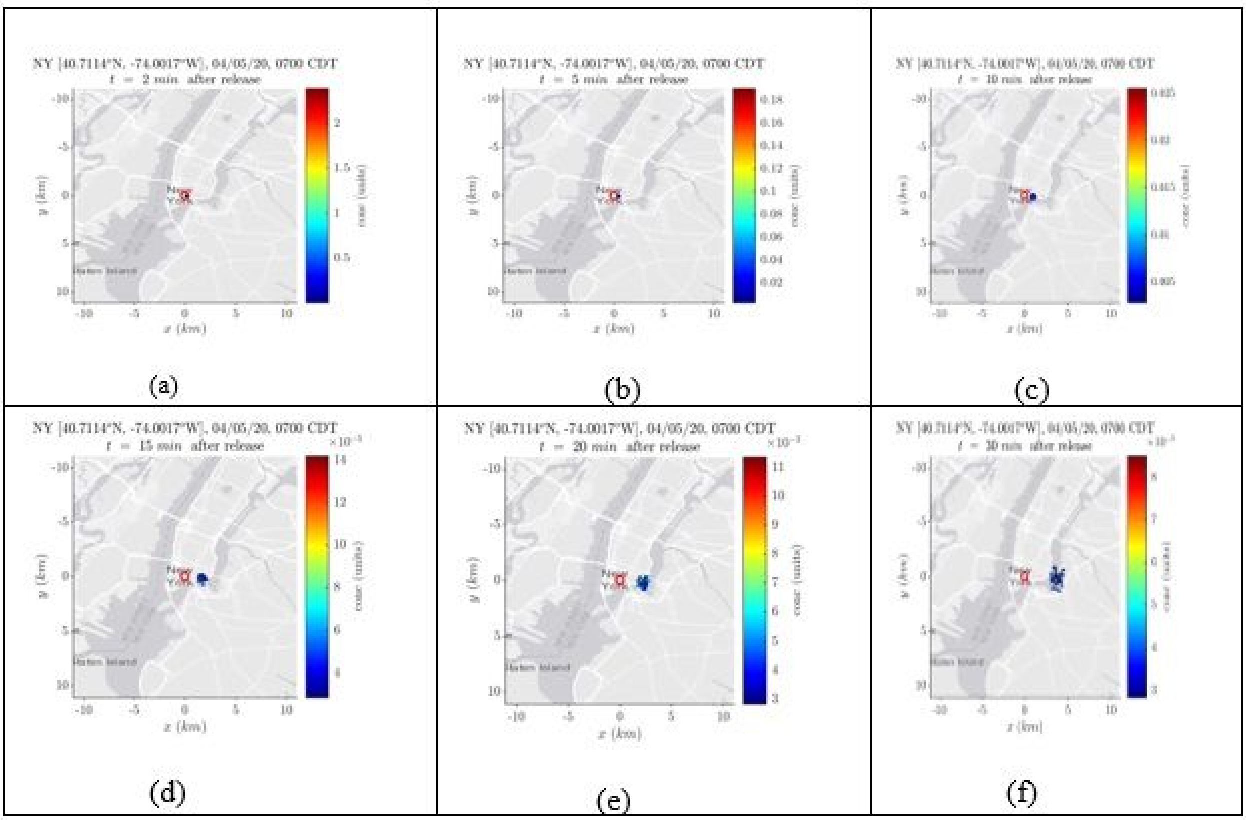

Figure 4

April 5, 0700 CDT Release (a) 2 minutes (b) 5 minutes (c) 10 minutes (d) 15 minutes (e) 20 minutes (f) 30 minutes

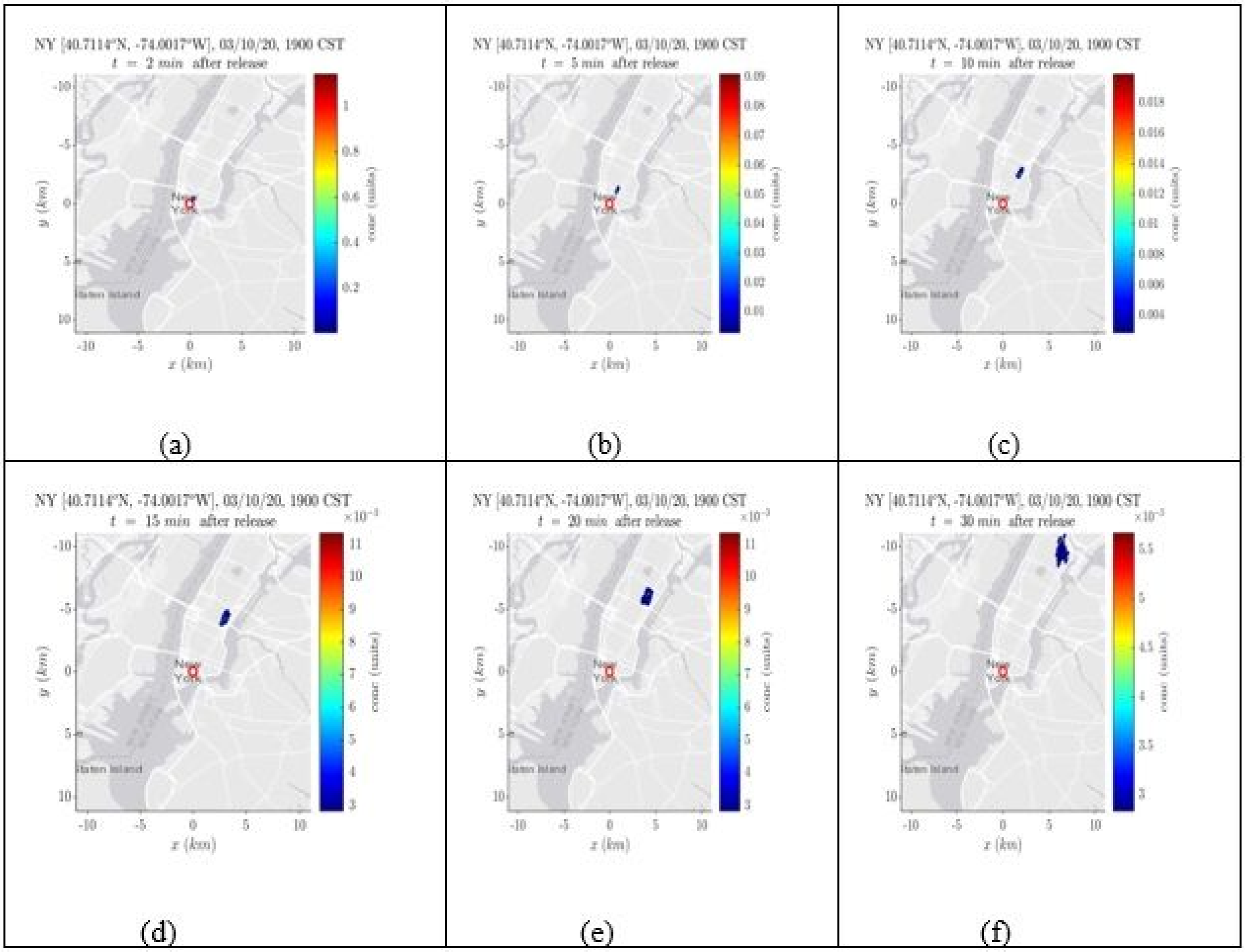

Figure 5

March 10, 1900 CDT Release (a) 2 minutes (b) 5 minutes (c) 10 minutes (d) 15 minutes (e) 20 minutes (f) 30 minutes

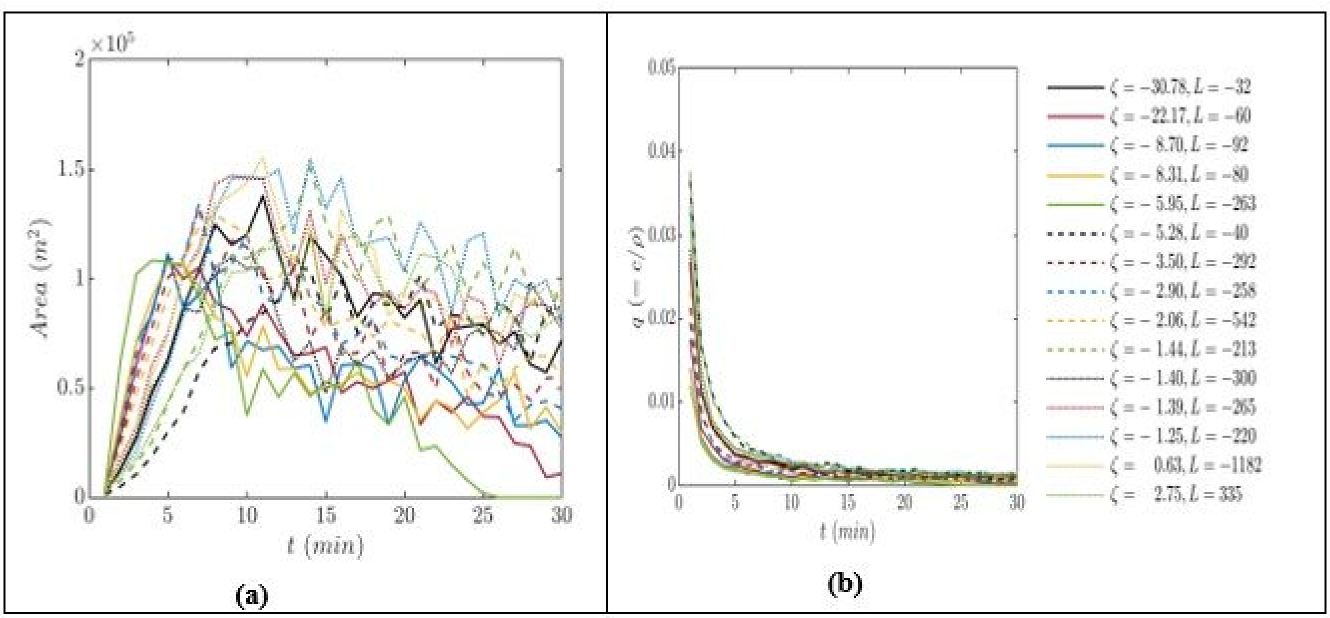

Figure 6

(a) Area covered by the virus-cloud at times (minutes) from the time of release, (b) mixing of the pollutant with the atmosphere in time (See Table 1).

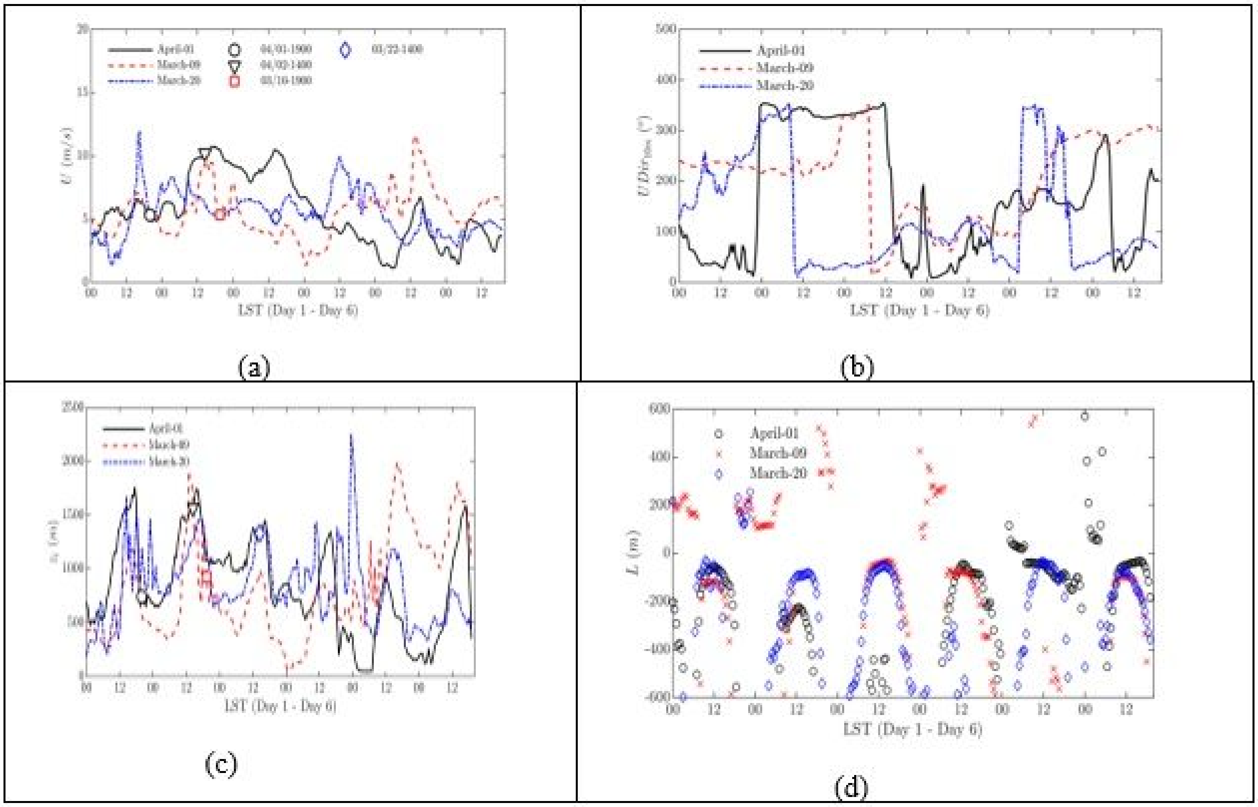

Figure 7

WRF simulation results for periods covering March 9-16, March 22- 26, April 1- 6: (a) Wind speed at 10 m height, (b) Wind direction at 10 m height, (c) PBL height, (d) Scale L

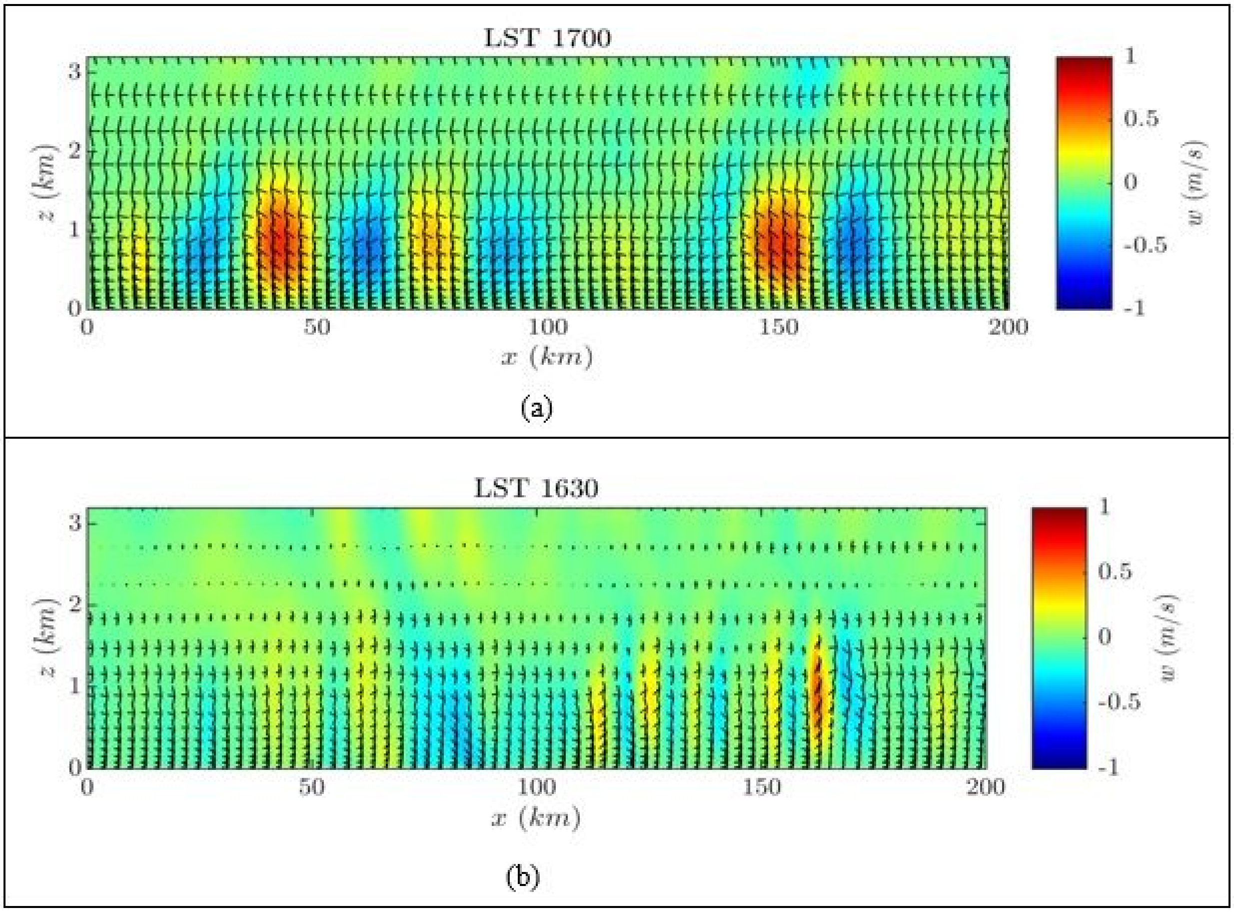

Figure 8

Horizontal roll (u-v vectors colored with w contours) at different time-instants of the WRF simulations: (a) April 4, 1700 hours CDT, (b) April 3, 1630 hours CDT.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- NY03221400CDT.mp4
- NY04021400CDT.mp4