ARL-TR-10111 • June 2025

User's Guide for the Atmospheric Boundary Layer Environment – Lattice Boltzmann Model (ABLE-LBM) Web Application Version 1.0

by Leelinda P. Dawson, Yansen Wang, and
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NOTICES

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ARL-TR-10111 ● JUNE 2025

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REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	END DATE
June 2025	Technical Report	1 October 2024	30 April 2025

4. TITLE AND SUBTITLE
User's Guide for the Atmospheric Boundary Layer Environment – Lattice Boltzmann Model (ABLE-LBM) Web Application Version 1.0

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

6. AUTHOR(S)
Leelinda P. Dawson, Yansen Wang, and Jonathan W. Decker

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
DEVCOM Army Research Laboratory ATTN: FCDD-RLA-NA Adelphi, MD 20783-1138	ARL-TR-10111

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES
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14. ABSTRACT
The Atmospheric Boundary Layer Environment – Lattice Boltzmann Model (ABLE-LBM) is the next-generation microscale atmospheric model developed by ARL to simulate and predict the atmospheric boundary layer's turbulent wind, temperature, moisture, and other scalar transports over complex terrain and urban areas. ABLE-LBM requires grid-rasterized terrain elevation, building, and vegetation data for the surface boundary information. This report serves as a user's guide by defining the software installation requirements and key functionalities of the first version of a geographical information system (GIS)-based GUI web application for ABLE-LBM. The application not only handles the tasks of controlling data preprocessing, running the model, and data postprocessing of the model's output to enable 2-D graphical visualization via Google Maps, but also creates building and vegetation data based on the images supplied by the GIS. The seamless integration of a GIS-based GUI with ABLE-LBM helps achieve the goal of simplicity and provides many enhanced functionalities for the application users.

15. SUBJECT TERMS
microscale atmospheric boundary layer modeling; terrain and urban data preprocessing; GIS application for atmospheric modeling; Network, Cyber, and Computational Sciences

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	C. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UU	29

19a. NAME OF RESPONSIBLE PERSON	19b. PHONE NUMBER *(Include area code)*
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STANDARD FORM 298 (REV. 5/2020)
Prescribed by ANSI Std. Z39.18

Contents

List of Figures

1. Introduction

The Atmospheric Boundary Layer Environment – Lattice Boltzmann Model (ABLE-LBM)[1–4] is the next-generation microscale atmospheric model developed by the U.S. Army Combat Capabilities Development Command Army Research Laboratory. It simulates turbulent atmospheric boundary layer wind, temperature, moisture, and aerosol transports over complex terrain and urban areas. The model results can be applied for unmanned aircraft system flight control, acoustic/optical wave propagations, and transport and dispersion of materials in the atmospheric boundary layer.

ABLE-LBM requires grid-rasterized terrain elevation, building, and vegetation data for the surface boundary information before running the model to predict atmospheric variables that are affected by the surface features. Thus, a Google geographical information system (GIS)-based GUI web application for ABLE-LBM[5] was developed to handle the data preprocessing, running the model, and data postprocessing of the model's output to enable the 2-D graphic visualization via Google Maps. This report serves as a user's guide by defining the software installation requirements and key functionalities of the first version for the ABLE-LBM GUI web application. It also explains how to use the application's graphic visualization system to display the ABLE-LBM's 2-D atmospheric variables on a Linux computer system via Google Maps. This allows the user to easily visualize and understand the output from ABLE-LBM to assist in decision-making.

2. System Installation Requirements

The ABLE-LBM GUI web application has six system installation requirements for the user to follow before successfully launching the application on their computer system. The following is the list of the installation requirements:

- Linux operating system
- Google Chrome web browser
- GNU[6] compiler
- Node.js[7] Version 10.24.0 or higher
  The user should download and install Node.js runtime environment by going to the following web page: https://nodejs.org and clicking on the "Download" link.
- Google Maps application programming interface (API) key
  The user needs to create a free Google Maps API key to use for the ABLE-LBM web application by using the instructions under the "Create API

Keys" section on the following web page: https://developers.google.com/maps/documentation/javascript/get-api-key. The user will need to create a Google/Gmail account to retrieve an API key, if they do not have one already. Google provides free monthly credit for all accounts per API key, which equals to approximately 28,000 usage requests per month. Most users of the ABLE-LBM web application should not exceed this amount per month. Then, the user should perform the following:

a) Copy the Google Maps API key from the new key listed on the "Credentials" page under the "API keys" section.
b) Save the Google Maps API key in the file, GoogleMapsAPIKey.txt, located in the "AppData" subdirectory of the application's distribution software package, so the application can automatically find the Google Maps API key when it is launched.

- High-resolution terrain data
  The user needs to use the U.S. Geological Survey (USGS) EarthExplorer[8] to search and download the terrain data sets. The ABLE-LBM terrain data processing automatically searches and interpolates the NASA Shuttle Radar Topography Mission (SRTM)[9] terrain elevation data (World Geodetic System 84 [WGS84]) for every grid point of the model domain. The 1 arcsecond SRTM data covers almost the entire land area of the earth globe from 56 south to 60 north latitudes.

  The ABLE-LBM web application's distribution software package contains a limited amount of SRTM terrain elevation data, which includes the areas of Baltimore, Maryland–Washington, D.C., and Huntsville, Alabama. However, if the user's domain of interest is an area outside one of these areas, then the application needs terrain elevation data for their domain. The user should download the required terrain elevation data from https://earthexplorer.usgs.gov and click on their area of interest. If the user does not have a USGS account, click on the "Login" link to register and create a USGS account by completing all the steps required by USGS.
  Then proceed as follows (shown in Figure 1):

  1) In the "1. Enter Search Criteria" section, click on the map for your area of interest or enter its latitude and longitude coordinates by selecting the "Degree/Minute/Second" or "Decimal" submenu of the "Polygon" menu and clicking on the "Add Coordinate" button.
  2) Click on the "Data Sets" button.

3) Under the “2. Select Your Data Set(s)” section, select “Digital Elevation,” “SRTM,” and “SRTM 1 Arc-Second Global,” which is the highest resolution SRTM data around 30 meters.
4) Click on the “Results” button.
5) The generated dataset will be listed under “Data Set” in the “4. Search Results” section. The user should click on the download icon to download the “BIL 1 Arc-second” data tile (circled in orange as shown in Figure 1). The downloaded SRTM data tile should be stored in the “AppData/SRTM_dat” subdirectory of the application’s distribution software package, so the application can automatically find the correct data tile for the user’s area of interest.

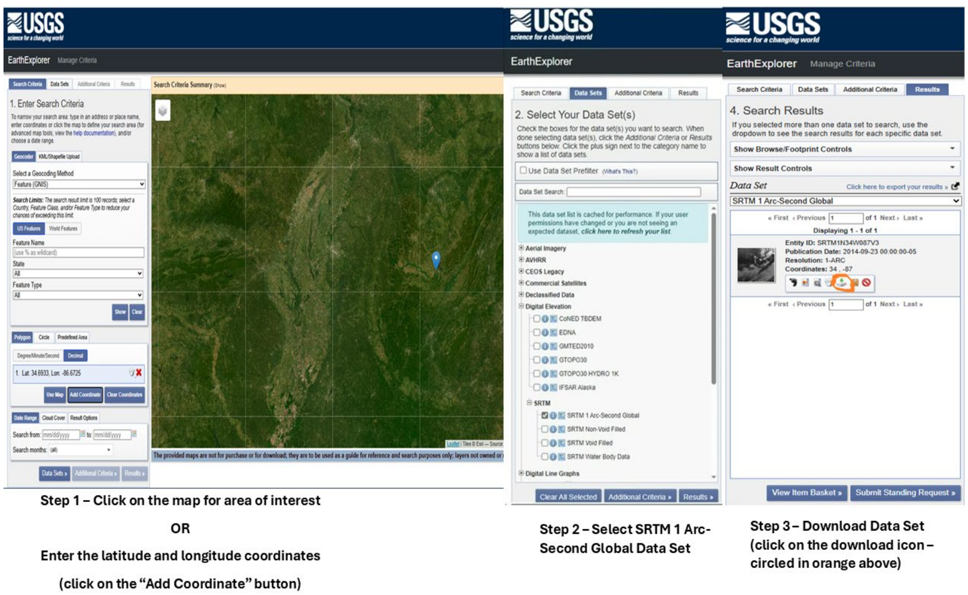

Figure 1. Download SRTM terrain elevation data on the EarthExplorer web site.

3. File Directory Structure

The software package for the ABLE-LBM web application contains shell scripts, a README file, and a subdirectory that contains all the files that are needed to run the application. The script uses are explained in this section as well as in Sections 4 and 5. The following is the file directory structure of the software distribution package:

- *install_nodejs_dps.sh* – Shell script to install the ABLE-LBM web application’s Node.js software dependencies
- *ABLE_LBM.sh* – Shell script to start the localhost server to run the ABLE-LBM web application

- *README* – Text file providing quick installation and instructions on running the ABLE-LBM web application
- *AppData* – Subdirectory containing all the input data, required ABLE-LBM executables, and output data files needed for the ABLE-LBM web application

4. Installing the ABLE-LBM Web Application

After completing the software installation requirements defined in Section 2, the user can install the ABLE-LBM web application on their computer system. When installing and running the application for the first time only, the user should run the following in the command prompt to install the required software dependencies for Node.js:

./install_nodejs_dps.sh

5. Launching the ABLE-LBM Web Application

To launch the ABLE-LBM web application, the user should perform the following steps:

- To start the localhost server for the application on a CPU computer system, enter the following in the command prompt:

  ./ABLE_LBM.sh

  This shell script will automatically display a message, such as "Server running at *http://localhost:<server_port_number>/*," which represents the localhost server and the server's port number (denoted by <*server_port_number*>) that is dynamically set by the application through the user's computer system. For example, in Figure 2, the server's port number is 34345.

  If the user has a GPU computer system and wants to run ABLE-LBM with a much faster execution time through the application, enter the following in the command prompt:

  ./ABLE_LBM.sh 2

- Go to your Google Chrome web browser and type *http://localhost:<server_port_number>* in the web address bar to launch the application, where <*server_port_number*> is the dynamic port number of the localhost server shown in the command prompt from Step 1.

After the application is successfully launched, the user can follow the previous two steps to simply start the localhost server in subsequent runs of the application, as necessary. The user has successfully launched the ABLE-LBM GUI web application when the main page of the application is displayed in the web browser (Figure 2).

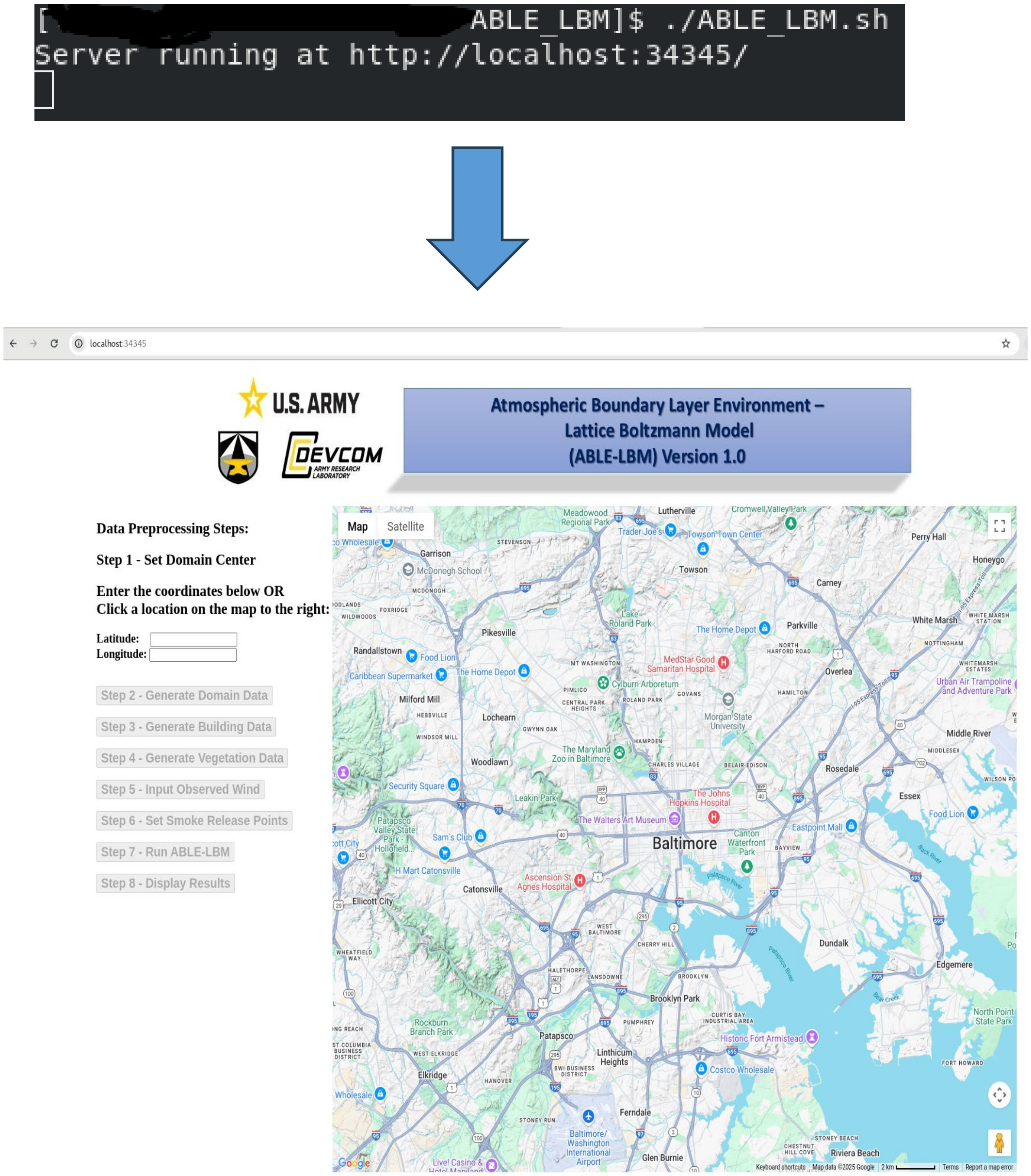

Figure 2. ABLE-LBM GUI application main web page after running the shell script.

6. Data Preprocessing Steps

There are six data preprocessing steps that need to be completed sequentially on the ABLE-LBM web application before the user can run the model and display its output in 2-D graphical visualization via Google Maps. The data preprocessing steps are listed in the area on the left side of the application's main web page (see Figure 2). Each step is defined by a button that the user clicks to complete each step. All the buttons on the main ABLE-LBM web page are automatically disabled until the user completes the first two steps of setting the domain center and generating the domain data. The buttons automatically turn green when the user completes each step.

The data preprocessing steps include setting the domain center for the user's area of interest; generating domain data, building data, and vegetation data; inputting the observed wind; and setting the smoke release points. Then, the user can use the final two button steps to run ABLE-LBM and automatically perform postprocessing to display the 2-D model output via Google Maps. All these steps are discussed in more detail in Sections 6.1–6.6 and subsequent sections.

6.1 Step 1: Set Domain Center

The first step in ABLE-LBM data preprocessing is for the user to set the domain center for their area of interest. There are two options for the user to set the domain center on the application. The first option is to set the domain center by entering the latitude and longitude coordinates in the text boxes on the left side of the application under "Step 1 - Set Domain Center." The application will automatically store and zoom into the domain center set by the user, which is denoted by a red ballon marker in the Google Maps area on the right side of the application (Figure 3). The user can seamlessly switch from "Map" and "Satellite" views as needed, which is indicated by the buttons located on the top left side of the Google Maps area. Similarly, the user can zoom in and out as needed by using the "+" and "–" buttons located on the bottom right side of the Google Maps area. The second option is for the user to set the domain center by clicking on a center point in their area of interest using the Google Maps area on the right side of the ABLE-LBM main web page. The application will automatically store and zoom into the domain center set by the user, which is denoted by a red ballon marker in the Google Maps area on the application like as described in the first option. Then, the button of the next step, "Step 2 - Generate Domain Data," will be automatically enabled for the user to proceed to generate the domain data.

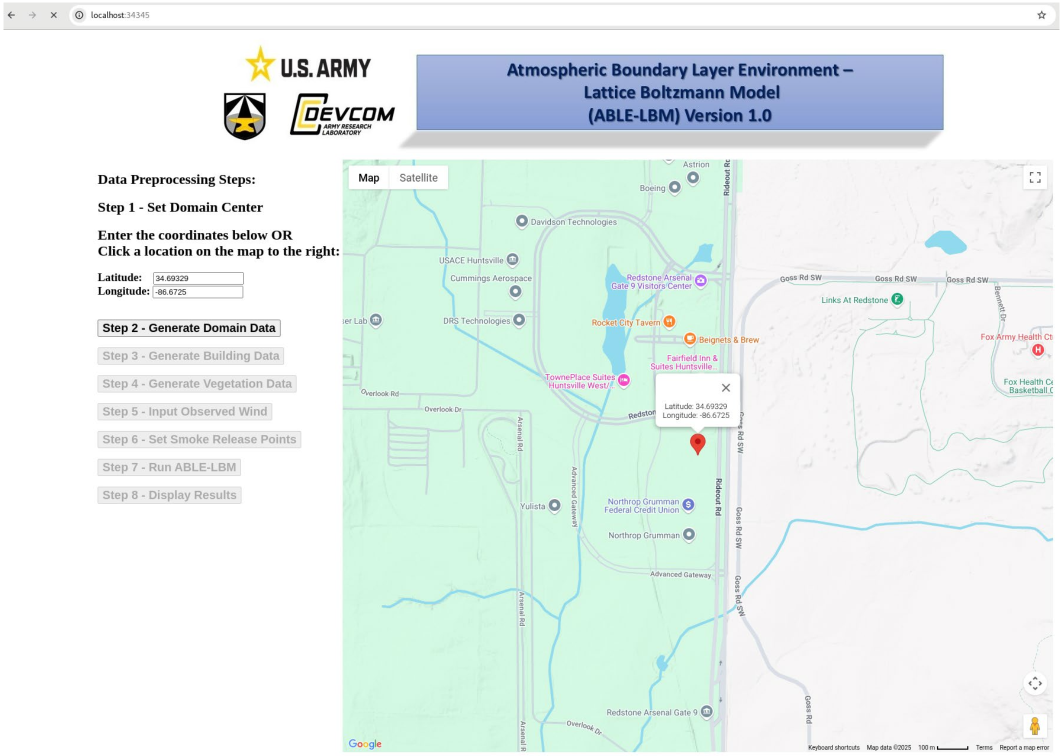

Figure 3. **Step 1 – set domain center.**

6.2 Step 2: Generate Domain Data

After setting the domain center, the second step in ABLE-LBM data preprocessing is for the user to generate data for the domain grid parameters of their area of interest by clicking on the "Step 2 – Generate Domain Data" button. After clicking on this button, a web page appears that allows the user to enter the domain grid parameters, which is the domain's grid separations and grid numbers (Figure 4).

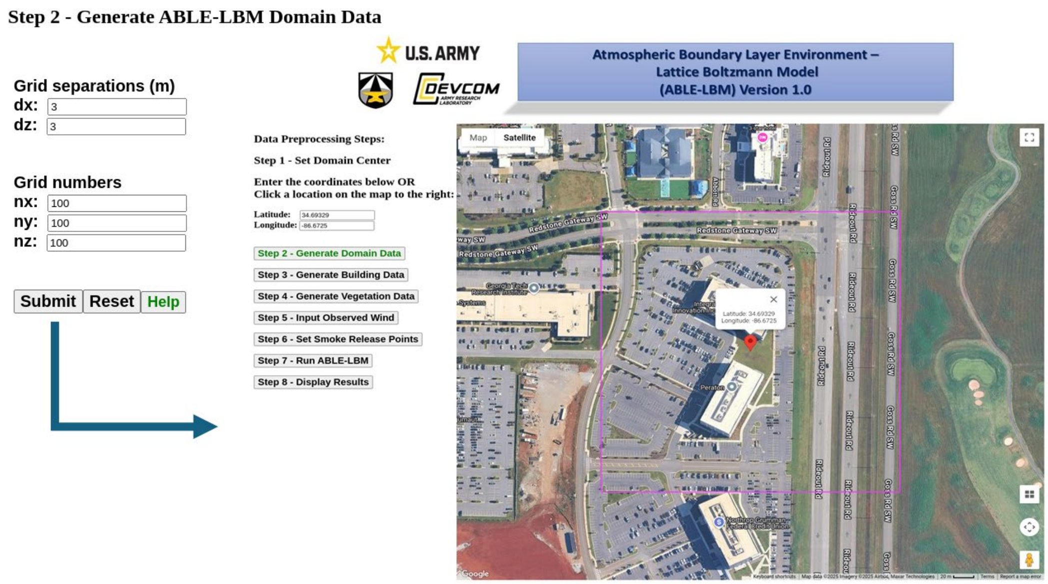

Figure 4. **Step 2 – generate domain data.**

The integer "dx" parameter (in meters) is the grid separation or length in the x-direction of the 3-D ABLE-LBM domain and the integer "dz" parameter (in meters) is the level or layer spacing in the vertical direction. The dx and dz grid separation should always have the same values. For example, if dx is set to 3 for the grid separation in meters, then dz should also be set to 3 for the grid separation in meters. The integer parameters nx, ny, and nz are the number of grid points in the x-, y-, and z-coordinate directions, respectively. After the user enters all the domain grid parameters for their area of interest, the user should click on the "Submit" button on the web page for the application to process and store the parameters. After the terrain elevation data processing is successfully completed, the application automatically displays a rectangle with a purple border representing the user's model domain using Google Maps (see Figure 4). If the user's domain is large, then the user will need to zoom out to view the whole domain containing the rectangle with the purple border. Next, the user should proceed with Step 3 to generate the building data.

6.3 Step 3: Generate Building Data

After generating the domain grid data, the third step in ABLE-LBM data preprocessing is for the user to generate data for all the buildings located in the user's domain by clicking on the "Step 3 – Generate Building Data" button. Note that the residential building data generation is not implemented yet in this version of the model. If there are no buildings located in the user's domain, the user should click on the “No Buildings” button as shown in Figure 5 and proceed to Step 4 to generate the vegetation area.

If there are buildings located in the user’s domain, the user should complete the form on the right of the ABLE-LBM Building Polygon Generator GUI. Then, zoom in and click on the map area to draw the building polygons as indicated on the GUI. This GUI collects additional preprocessing information of the grid interpolation for building data generation.[2] It captures information through the user’s input about all the buildings located in the user’s domain within the purple border as shown in Figure 5.

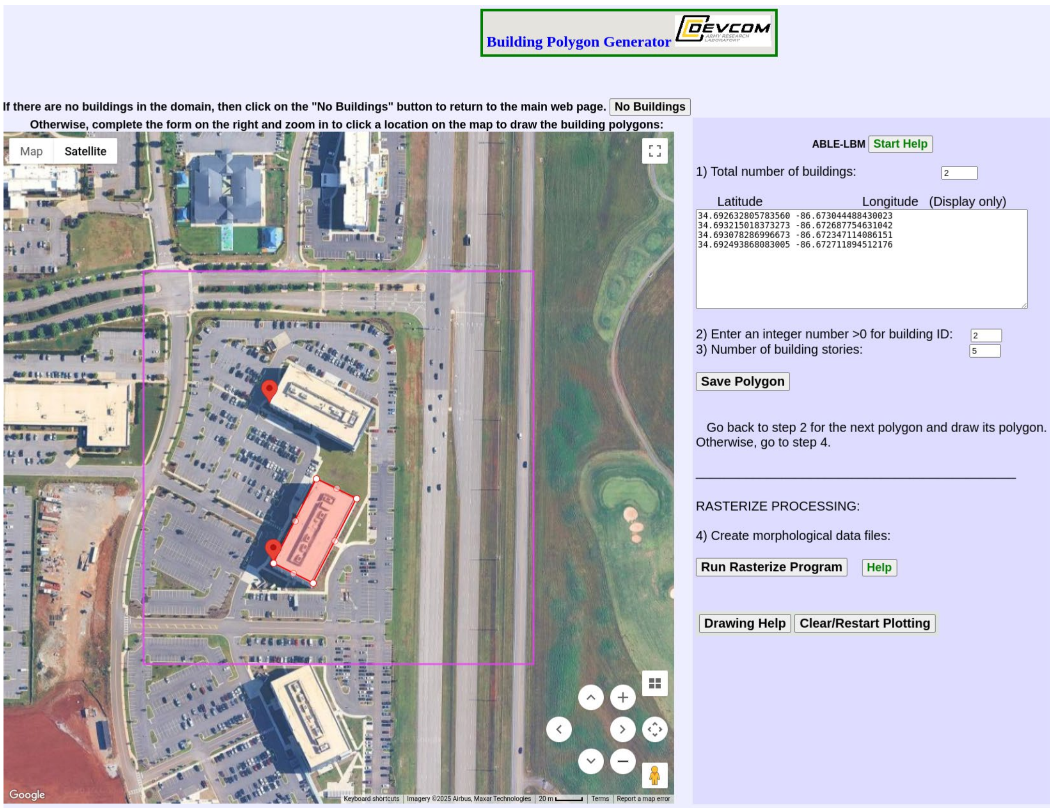

Figure 5. Step 3 – generate building data.

The building information is obtained by the user on the GUI by performing the following:

- Enter the total number of buildings of interest in the domain.
- For each building:

  a) Draw a polygon to collect the geocoordinates (or the latitude and longitude points) of the building corners. The geocoordinates are retrieved by the user mouse-clicking on the Google Maps area to plot clockwise from a corner and draw a polygon of the building’s roof on the GUI. The user should zoom in as close as possible to accurately draw the building's polygon. Also, the user should make sure to only draw polygons for buildings located within the purple border lines of the domain and omit drawing polygons for buildings that are too close to the border lines. The user has the option to clear and restart the drawing of the buildings by clicking on the "Clear/Restart Plotting" button on the bottom of the GUI, if needed.

b) Enter the building identifier (ID) number, which can be any number greater than zero.

c) Enter the number of building stories.

- Once all the building's information and the drawn polygon are entered and completed on the GUI, the user should click on the "Save Polygon" button for the application to save the building's drawn polygon. A red marker will be displayed on the lower left corner of the building to indicate the drawn polygon has been saved by the application.
- Repeat Steps 2 and 3 for the next building (if applicable) until all the information and drawn polygons about all the buildings in the user's domain have been entered and completed on the GUI.
- Once all the drawn building polygons are completed in the user's domain, the user should click on the "Run Rasterize Program" to complete the building data generation and return to the ABLE-LBM main web page to proceed with Step 4 to generate vegetation data.

6.4 Step 4: Generate Vegetation Data

The fourth step in ABLE-LBM data preprocessing is for the user to generate data for all the vegetation areas located in the user's domain by clicking on the "Step 4 – Generate Vegetation Data" button. If there are no vegetation areas located in the user's domain, the user should click on the "No Vegetation Areas" button as shown in Figure 6 and proceed to Step 5 to input the observed wind.

If there are vegetation areas located in the user's domain, the user should complete the form on the right of the ABLE-LBM Vegetation Polygon Generator GUI. Then, zoom in and click on the map area to draw the vegetation area polygons as indicated on the GUI. This GUI collects additional preprocessing information of the grid interpolation for vegetation data generation.[2] It captures information through the user's input about all the vegetation areas located in the user's domain within the purple border, as shown in Figure 6.

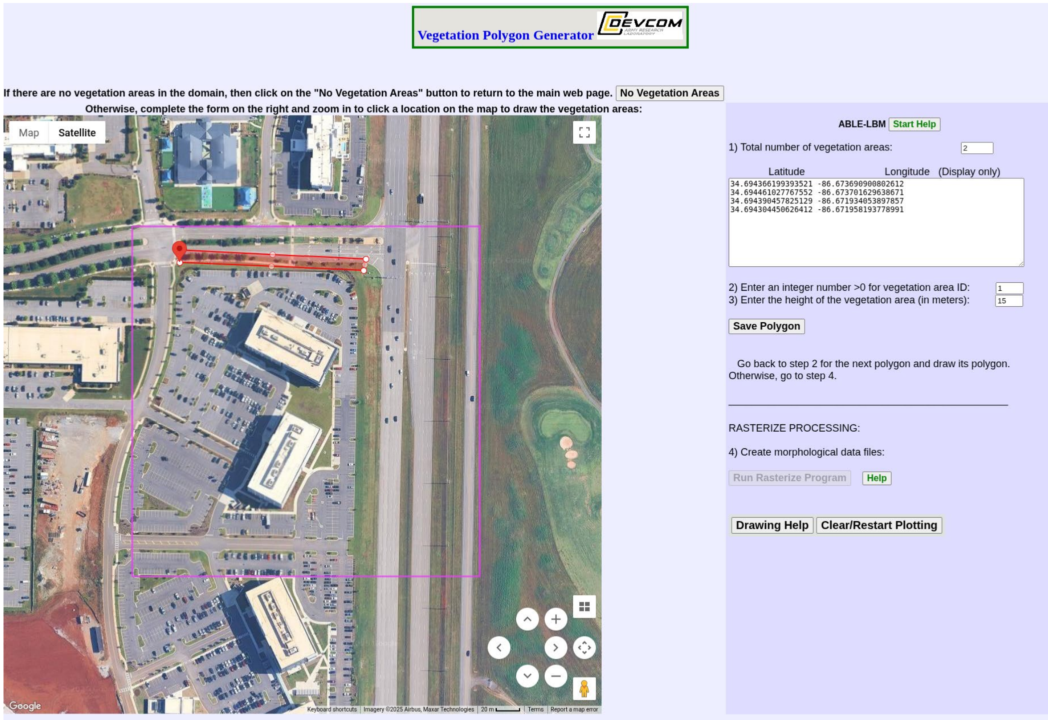

Figure 6. Step 4 – generate vegetation data.

The information about the vegetation areas is obtained by the user on the GUI by performing the following:

- Enter the total number of vegetation areas of interest in the domain.
- For each vegetation area:

  a) Draw a polygon to collect the geocoordinates (or the latitude and longitude points) of the vegetation areas. The geocoordinates are retrieved by the user mouse-clicking on the Google Maps area to plot clockwise from a corner and draw a polygon for the vegetation area on the GUI. The user should zoom in as close as possible to accurately draw the vegetation area's polygon. Also, the user should make sure to only draw polygons for vegetation areas located within the purple border lines of the domain and omit drawing polygons for vegetation areas that are too close to the border lines. The user has the option to clear and restart the drawing of the vegetation area by clicking on the "Clear/Restart Plotting" button on the bottom of the GUI.
  b) Enter the vegetation area ID number, which can be any number greater than zero.
  c) Enter the height of the vegetation area in meters.

- Once all the vegetation area's information and the drawn polygon have been entered and completed on the GUI, the user should click on the "Save

Polygon" button for the application to save the vegetation area's drawn polygon.

- Repeat Steps 2–3 for the vegetation area (if applicable) until all the information and drawn polygons about all the vegetation areas in the user's domain have been entered and completed on the GUI.
- Once all the drawn vegetation area polygons have been completed in the user's domain, the user should click on the "Run Rasterize Program" to complete the vegetation data generation and return to the ABLE-LBM main web page to proceed with Step 5 to input the observed wind.

6.5 Step 5: Input Observed Wind

The fifth step in ABLE-LBM data preprocessing is for the user to input the observed wind parameters for their domain by clicking on the "Step 5 – Generate Initial Boundary Parameters" button. When the user clicks on this button, a web page will appear that allows the user to enter the observed wind parameters, which is the observation point height and the observed u and v wind components, as shown in Figure 7. The meteorology convention for wind components is u (positive direction: from west to east), and v (positive direction: from south to north). Note that the simple point inputting of observed wind is only for this first version of the ABLE-LBM web application, which is for neutral atmospheric flow. The single point was extrapolated to a vertical profile throughout the vertical direction to the domain top representing the inflow wind profile. More accurate wind inflow will be delivered in the next version of the application.

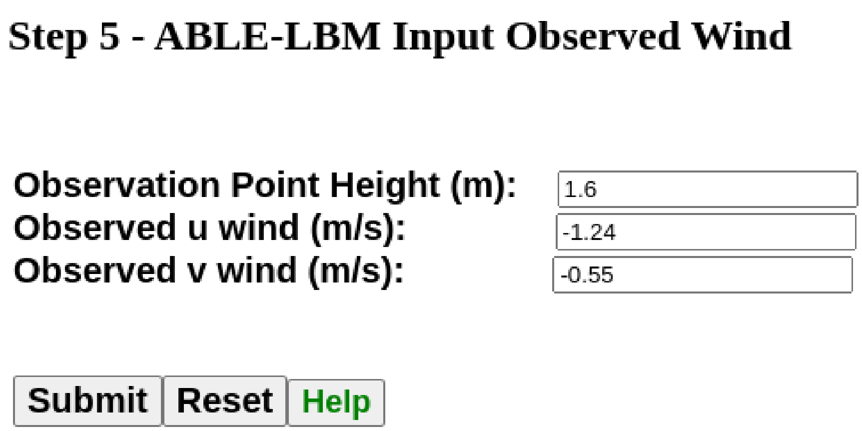

Figure 7. Step 5 – input observed wind.

The observation point height (in meters) is the height of the above-sea-level elevation of the observation point, where the wind is being observed. The observed u wind and v wind are the u and v wind components (in meters per second [m/s]) that the user has observed through reading an anemometer. The anemometer reading usually uses the magnetic north, therefore the user should make sure to transform the wind direction from magnetic north to true north,[10] according to your geographic location. After entering all the observed wind parameters, the user should click on the "Submit" button (see Figure 7) to save all the parameters to return to the ABLE-LBM main web page. Then, the user can proceed with Step 6 to set the smoke release points.

6.6 Step 6: Set Smoke Release Points

The sixth step in ABLE-LBM data preprocessing is for the user to set the latitude and longitude locations of the ground or air smoke release points for their domain. If there are no smoke release points in the user's domain, then the user should click on the "No Points" button (Figure 8) to return to the ABLE-LBM main web page to proceed to Step 7 to run ABLE-LBM.

If there are smoke release points in the user's domain, then the user should complete the form displayed on the form, as shown in Figure 8, by selecting the type of release point (ground or air) and air release elevation (in meters), if applicable. The user should not enter an elevation value when selecting ground as the type of release point. Next, the user should click on the map to set the location of the ground or air smoke release point. The ground release points will be denoted with yellow markers and air release points will be denoted with blue markers. For example, as shown in Figure 8, there were three release points set—one being a ground release point (i.e., yellow marker) with the other two being air release points (i.e., blue markers). If there are any additional smoke release points in the user's domain, the user should repeat the same steps for the next smoke release points. When the user is finish setting all the smoke release points, they should click on the "Submit" button to save the release points and return to the ABLE-LBM main web page. Then, the user can proceed with Step 7 to run ABLE-LBM as discussed in Section 7.

Figure 8. Step 6 – set smoke release points.

7. Step 7: Run ABLE-LBM

After the completion of all six ABLE-LBM data preprocessing steps, the seventh step is for the user to run ABLE-LBM by clicking on the "Step 7 – Run ABLE-LBM" button. The user should wait until ABLE-LBM has finished running, which can take from a couple of seconds to many minutes depending if the user is using a CPU or GPU computer system. The user can view the application's console log (Figure 9) to check the completion status of running ABLE-LBM.

After the user has completed running ABLE-LBM, then the application will automatically change the "Step 7 – Run ABLE-LBM" button on the ABLE-LBM's main web page to green to indicate successful completion as shown in Figure 9. Then, the user can proceed to Step 8 to display the ABLE-LBM results.

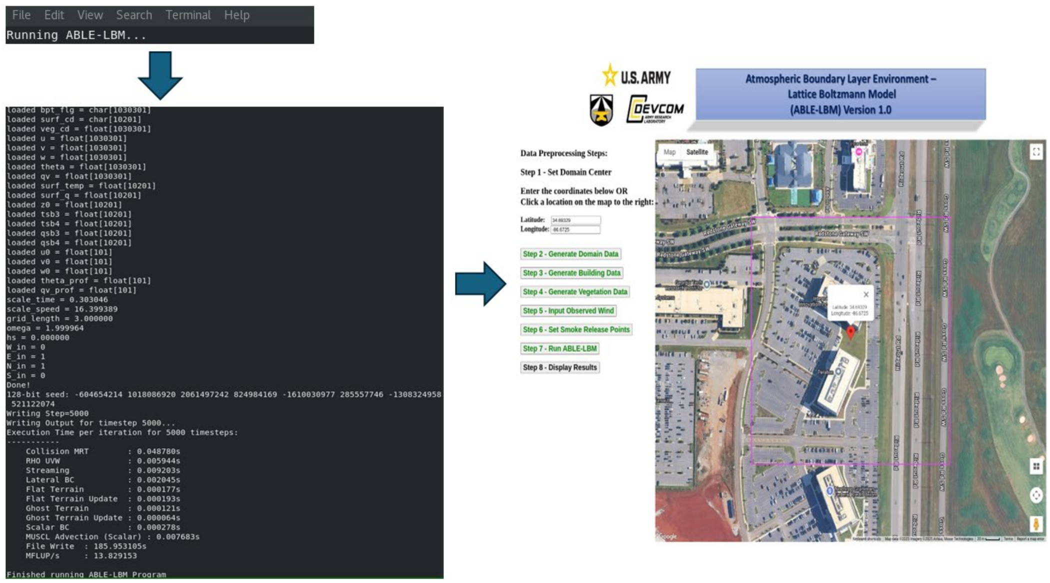

Figure 9. Step 7 – run ABLE-LBM.

8. Step 8: Display Results

The final and eighth step is for the user to display the ABLE-LBM's results on the application by clicking on the "Step 8 – Display Results" button. When the user clicks on this button, the application automatically performs postprocessing of the ABLE-LBM results, then displays the ABLE-LBM Extensible Markup Language (XML) results in 2-D via Google Maps on the application.

The user displays the ABLE-LBM results by clicking on the drop-down menu on the "Display Results" web page (Figures 10 and 11). By default, 2 m above-ground level is set to display when the user first clicks on the "Step 8 – Display Results" button. The ABLE-LBM results display options are 2 m above-ground surface (terrain following), and model horizontal layers from 1 to *nz*, which was previously set as a domain grid parameter in Step 2 of the ABLE-LBM data preprocessing (see Section 6). The height of elevation for each *nz* layer is calculated in meters during ABLE-LBM postprocessing and are displayed dynamically on the application in parentheses by each layer as shown in Figures 10 and 11. The arrow vectors for the user's domain will always be displayed with red arrows in Google Maps depicting the wind direction with the 10 m/s scale vector label at the lower left corner of the user's domain (depicted by a purple border) as shown in Figures 10 and 11. If there is any smoke concentration in the user's domain at the selected layer, then a green to yellow to red color bar is shown on the web page, which depicts the lowest to the highest range of smoke concentration normalized by point source strength within the user's domain using smoke contours in Google Maps. The concentration ranges for the color bar are variable and calculated during the postprocessing of the ABLE-LBM results before it is shown on the "Display Results" web page. The color-coded smoke contours are automatically displayed in Google Maps showing the different ranges of normalized smoke concentrations for the user's domain.

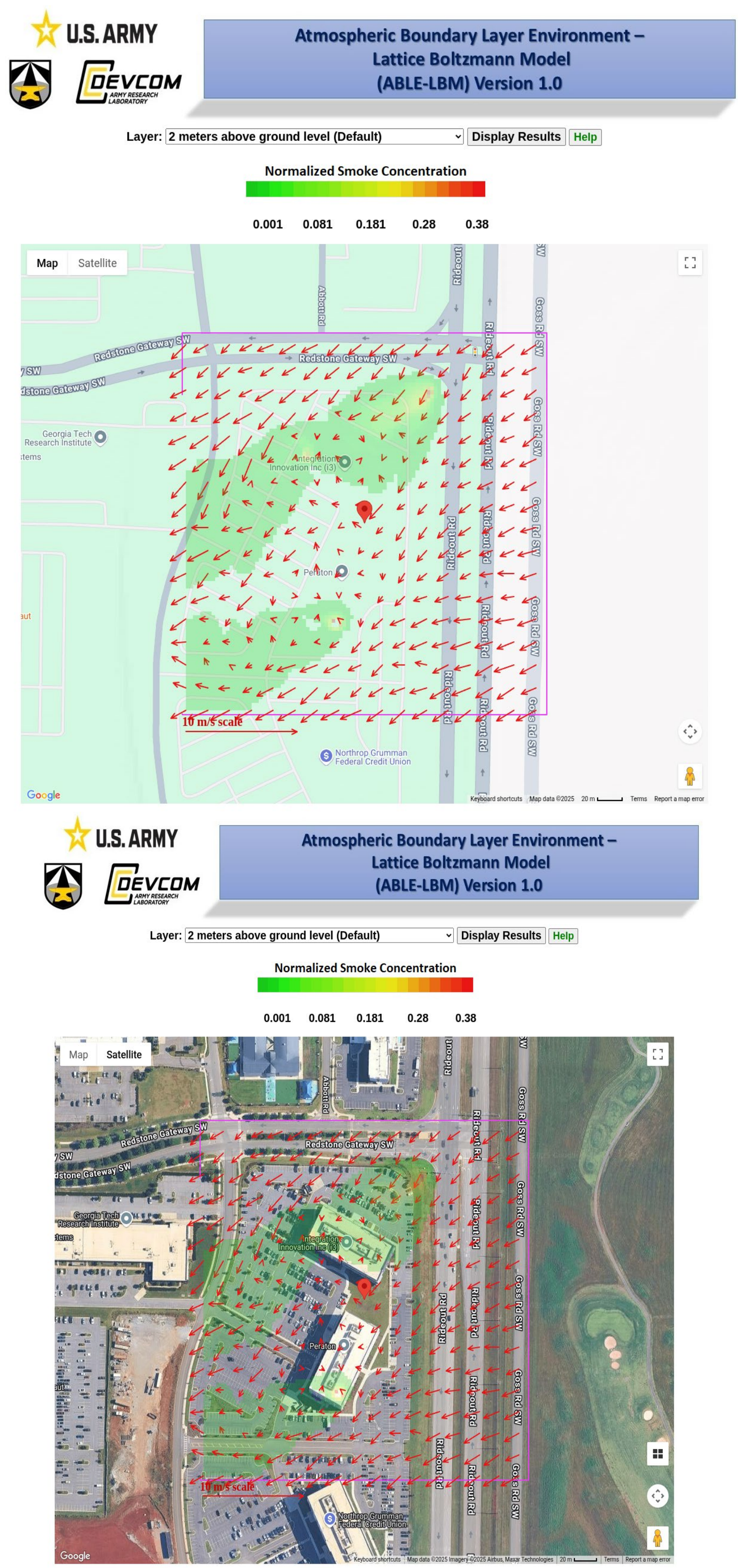

Figure 10. Step 8 – display results examples at 2 m above-ground-level terrain view (top) and satellite view (bottom) maps with smoke contours.

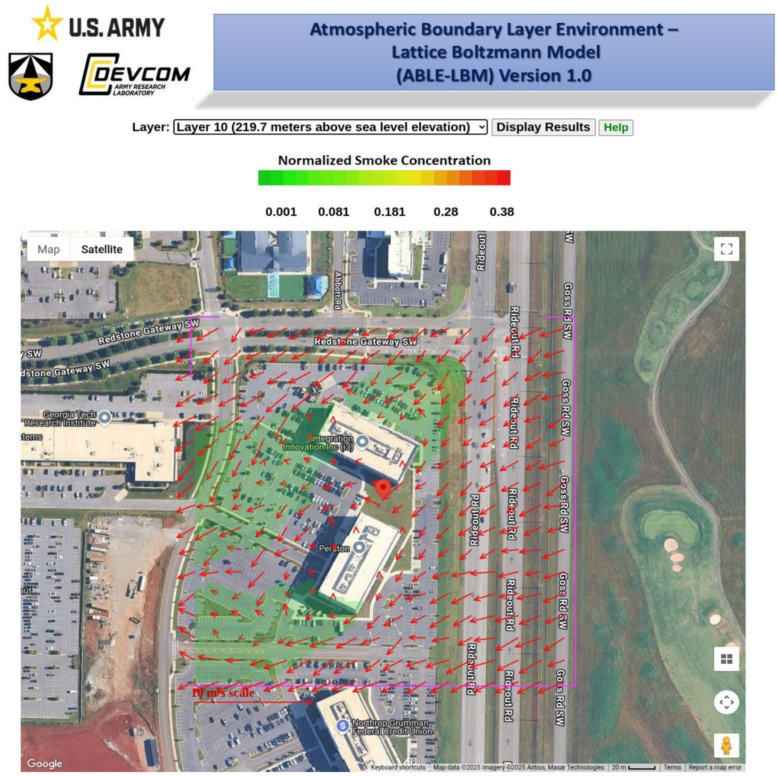

Figure 11. Step 8 – display results example at layer 10 (219.7 m above-sea-level elevation) satellite view map with smoke contours.

If there is no smoke in the user's domain at the selected layer, the red arrow vectors will only display in the Google Maps and a red text label will display on the web page stating, "There is no smoke at layer <number>!", where <number> represents the selected layer number where there are no smoke contours present in the user's domain (Figure 12).

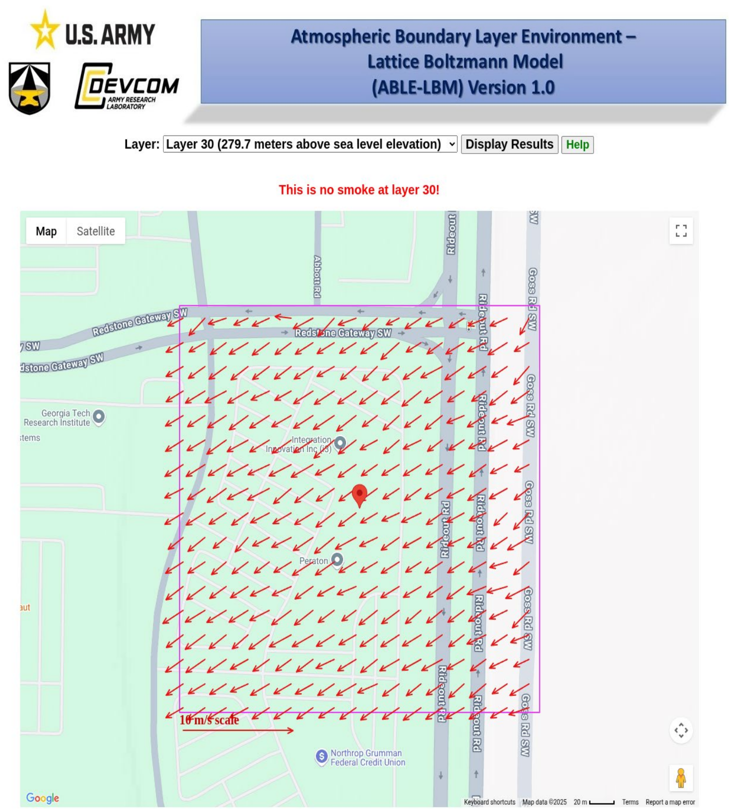

Figure 12. Step 8 – display results example at layer 30 (279.7 m above-sea-level elevation) terrain view map with no smoke contours.

9. Conclusion and Future Work

ABLE-LBM, developed by the DEVCOM Army Research Laboratory, is the next-generation atmospheric microscale model that simulates and predicts the atmospheric boundary layer's turbulent wind, temperature, moisture, and other scalar transports over complex terrain and urban areas. The application processes the required input data from six preprocessing steps to the model, then runs ABLE-LBM to postprocess the output data produced by the model so it can be displayed on the 2-D graphic visualization system via Google Maps. This allows the user to easily visualize and understand the atmospheric variable fields output from ABLE-LBM to assist in decision-making.

The future work of the ABLE-LBM web application involves the continuation of developing and improving the application, which includes the automation of downloading the SRTM terrain data from the USGS EarthExplorer web site and improving its graphic visualization system through 3-D animation. Also, the non-neutral atmospheric flow, which includes the temperature and moisture effects, will be implemented in the next version of the application, since the first version of the application is only for neutral atmospheric boundary layer flows and transport.

Furthermore, additional research and development are required for the ABLE-LBM GUI web application to be fully functional on Windows computers as another platform option. Future work also includes further developments of GUI controls with data input, processing, and display of other atmospheric variables such as temperature and moisture.

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List of Symbols, Abbreviations, and Acronyms

2-D/3-D	two-/three-dimensional
ABLE-LBM	Atmospheric Boundary Layer Environment – Lattice Boltzmann Model
API	application programming interface
ARL	Army Research Laboratory
CPU	central processing unit
DEVCOM	U.S. Army Combat Capabilities Development Command
GIS	geographical information system
GPU	graphics processing unit
GUI	graphical user interface
ID	identifier
m/s	meters per second
NASA	National Aeronautics and Space Administration
SRTM	Shuttle Radar Topography Mission
USGS	U.S. Geological Survey
WGS84	World Geodetic System 84
XML	Extensible Markup Language

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