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Haze Trajectory Simulation System from Forest and Land Fires in Indonesia Using HYSPLIT

Imas Sukaesih Sitanggang[1,*], Apriliantono[1], Lailan Syaufina[2], Muhammad Asyhar Agmalaro[1], Husnul Khotimah[1]

[1]Department of Computer Science, IPB University, Indonesia
[2]Department of Silviculture, Faculty of Forestry and Environment, IPB University, Indonesia

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Abstract Haze is one of the harmful consequences of forest and land fires that cause negative effects on human health. In addition, the increase of CO_2 produced by forest and land fires in the atmosphere results in the greenhouse effect. To minimize the negative consequences of forest and land fires, analysis of haze movement and pollutant concentrations is necessary to be performed. This study aims to develop a web-based application for clustering haze trajectories from forest and land fires in Sumatra in 2015. The data used for the simulation are hotspot sequential patterns in Sumatra in 2015 and weekly GDAS meteorological data. This study adopts the linear sequential model in system development, which consists of four stages: analysis, design, implementation, and testing. The application was implemented using the Shiny Framework, which is available in the R programming tool. Two clustering algorithms are implemented in the application, namely ST-DBSCAN and K-Means. Haze and pollutants, including CO and CO_2, were generated using the HYSPLIT model. The application has three main features: Generating Haze Trajectory, Haze Clustering, and Haze Cluster Visualization. The system was tested, and the results show that all features in the application are working correctly. The system has a limitation in generating the real-time haze trajectory. This is due to the availability of real-time hotspots as initial points of simulations and meteorological data. Future work will focus on developing a real-time application of haze trajectory from forest and land fires.

Keywords Clustering, Forest and Land Fires, Haze, HYSPLIT, Shiny Framework

1. Introduction

Forest and land fires in Indonesia, especially in Sumatra and Kalimantan, are recurring events almost yearly. Some factors that underlie peatland fires in Indonesia are accidental fire by humans and intentional combustion to clear land to cultivate more profitable crops. Another factor that supports peatland fires is extreme weather, which can increase the negative impacts of the fires. Indonesian Institute of Science [1] states that peatland fires in Riau in 2015 caused emergency air pollution status, where the thickness of peatland becomes one of the causes why smoke haze is difficult to extinguish. Moreover, Terra and Aqua satellites recorded as many as 1143 hotspots on 14 September 2015 in the region of Sumatra [2]. In this situation, visibility was obscured with smoke, and this condition caused bad air quality. The negative impacts caused by peatland fires include damage to the sustainability of the ecosystem in the affected area and the production of smoke and haze from the fires. This smoke and haze can harm human health, causing respiratory problems. According to data from the Information Center of the Ministry of Health Indonesia [3], from June 29 to October 29, 2015, Acute Respiratory Infections (ISPA) in Riau accounted for the most significant proportion of the health effects of smoke and haze, reaching 83.92%. Furthermore, the increased emissions from peatland fires can pose hazards beyond health concerns, as they also disrupt visibility and impact the activities of sea and air transportation activities.

Clustering algorithms have been applied to haze trajectory and pollutant datasets [4, 5]. Haze dispersion and pollutant concentration are essential in preventing the negative impacts of peatland fires. Khairat et al. [4] determined the haze trajectory patterns from peatland fires in Riau Province in 2015 using the HYSPLIT model. The simulation results in 4887 positions of haze that move to the northeast and northwest. The haze trajectory datasets were grouped using the K-Means algorithm. The clustering results show that the largest cluster has positions of haze, and these haze movements are located at an average height of 23.554 meters Above Ground Level (mAGL). Those haze positions were in Riau, North Sumatra, Malaysia, and Malacca Strait [4].

Niam et al. [5] applied the K-Means algorithm to cluster and analyze the concentration of CO and CO_2 produced by peat fires in Sumatra in 2015. The concentration of CO and CO_2 was generated using the HYSPLIT model. The results show that the average of the highest concentration of CO is 11.1471 $\mu g/m^3$, and CO_2 is 88.5882 $\mu g/m^3$. Generally, pollutants have an average concentration of 0.0487 $\mu g/m^3$ for CO and 0.3687 $\mu g/m^3$ for CO_2. The pollutant concentration spread on 45,525 haze locations, starting from Riau to Nanggroe Aceh Darussalam.

Sitanggang et al. [6] performed a simulation based on the HYPLIT model to generate haze trajectories from fires in South Sumatra using the package Opentraj, available in R. The results show that haze from fires in South Sumatra affected not only people in this province but also in neighboring provinces, namely Jambi, Riau, West Sumatra, and North Sumatra. The simulation to generate haze trajectory in the previous studies [4, 6] was done using the desktop application, which wider users could not use.

The applications of HYSPLIT for haze dispersion simulation have been done in several studies. Luo and Chen [7] examined the potential sources and PM2.5 dispersion paths in the Shanghai, China area from January 2013 to December 2014 using the HYSPLIT, K-Means clustering, and concentration-weighted trajectory (CWT) models. The HYSPLIT model was also used to identify the emissions, transport, dispersion, and decomposition of heavy metals in aerosol atmospheres originating from large industrial estates in the southern part of the Spanish state [8].

Shiny is a framework for developing interactive web-based applications from R software. In our previous studies, Abriantini et al. [9] utilized the Shiny framework to build web-based applications for applying data mining techniques in hotspot datasets. Those applications consist of two main files: Server.R as a server file and UI.R as a web-based application to visualize hotspot sequence patterns in the peatland of Sumatra and Kalimantan. The application has main features for plotting sequence patterns based on peatland characteristics in Sumatra, peatland characteristics in Kalimantan, weather data, and socio-economic data.

A web interface using the Shiny framework was developed by Darmawan et al. to implement the Generalized Additive Mixed Model (GAMM) in analyzing the effect of the total rainfall, harvest area, and population density on rice production [10]. R shiny framework was also used to conduct Covid-19 analysis in Java using the Spatial Durbin Model [11]. ChroKit, a Shiny-based system, was developed by Croci and Companer for interactive analysis, visualization, and genomic data integration [12]. Klein et al. [13] built the webEXTREME to calculate the extreme agro-climate index, namely assessing extreme agricultural climates related to extreme temperatures and drought, using Shiny to build web applications. The R programming was chosen because of its popularity in data analysis and the availability of packages for integration purposes. Moller et al. [14] developed the PhenoWin using R programming language and the R Shiny web framework. PhenoWin is a tool for extracting and visualizing phenological windows for a specific time and region defined by a user in Germany. Application systems are developed to increase the need for small-scale information regarding the temporal shift from developing plant phenology to applications such as fertilization, irrigation, crop and soil protection, weather index insurance, yield prediction, crop classification, or as a bioindicator of climate change. Luz et al. [15] used the R programming language and package Shiny to implement the Rapid Analysis of Diagnostic and Antimicrobial Patterns in the R (RadaR) web application framework. RadaR allows interactive visualization of analytical graphs and descriptive statistics. It will enable users to screen patients with 17 different criteria and classes of antimicrobial use, user of microbiological diagnostics and outcomes including antimicrobial resistance, and outcome in length of stay. Based on the references, this research has tried and utilized the shiny framework to build a web-based dashboard application for haze trajectory pattern mining from forest and land fires.

2. Methods

This study uses the hotspot sequence discovered on the dataset [9]. Abriantini et al. [9] generated hotspot sequential patterns in Sumatra and Kalimantan in 2014 and 2015 with a minimum support of 0.01. The results are 89 sequences with a length of 2 or more in Sumatra in 2014, 147 sequences in Sumatra in 2015, 48 in Kalimantan in 2014, and 51 in Kalimantan in 2015 [9].

This study focuses on sequential patterns in Sumatra in 2015 that have a length of two or more events. Hotspots that occur sequentially in at least two days are considered strong indicators for burning peatland.

The system development adopts the linear sequential model, which consists of four stages: analysis, design, implementation, and testing. Those four stages are briefly described as follows.

2.1. System Analysis

In this stage, this study conducted a requirement analysis of the application. System requirements include determining hotspot sequence patterns, performing HYSPLIT model simulation, setting parameters for clustering, performing spatiotemporal clustering, and displaying the clustering results and cluster evaluation. System requirements were also performed for the Graphical User Interface (GUI) and software utilized in the application development.

2.2. System Design

We designed the application, database, and interface process in this step. This stage is expected to understand better data flow from the database, processes of each function built into the system, and information in the system. The system requires several input parameters in trajectory generation and clustering. The first parameter is the period of hotspot occurrence. The system evaluates the availability of hotspot databases to obtain hotspot sequence patterns and meteorological datasets in the same period as hotspot sequences. Furthermore, the system performs a trajectory simulation using the HYSPLIT model. The second parameters are those required by the clustering algorithm ST-DBSCAN and K-Means. The system then runs those two clustering algorithms on trajectory patterns and pollutant concentrations. The system displays results of ST-DBSCAN and K-Means, including haze and pollutant clusters.

2.3. System Implementation

The selected software implements all system design results, including functions, database, and interface. R version 3.2.5 and RStudio are used to develop the application. R’s packages used include fpc for evaluating pollutant concentrations as the emission of peatland fires, Shiny framework for developing a web-based dashboard application, Shiny framework themes for creating a theme on the user interface of the system, SplitR for simulating trajectory patterns and pollutant concentrations, RPostgreSQL for connecting the database, which PostgreSQL manages, Leaflet for visualizing Google Maps on the application of Shiny framework, and psych for calculating descriptive statistics of observed variables. In addition, HYSPLIT version 4.9 is utilized to generate trajectory patterns and pollutant concentrations as emission gases from peatland fires. PostgreSQL, a database management system, manages meteorological datasets and hotspot sequence patterns.

Shiny is a package from the R programming language to build web-based applications. Shiny easily provides data summaries and queries for users through a web browser. Shiny coming with widgets for creating interactive user interfaces, is highly extensible, and Shiny applications are easy to integrate with HTML and CSS. JavaScript and JQuery can also be used to extend the scope of the Shiny application [16]. Shiny is a package of a web framework that simplifies web application development using the programming language R. Shiny displays the result of analysis and visualization in graphics and can display output according to input without adding another page. Shiny consists of two parts, namely the interface and the server. The interface is used to manage the application interface, while the server part executes commands as functions. The design phase was made in R software using the Shiny Package. This web-based application was built using the Shiny framework, which consists of two components: file server.r and ui.r. The file server.r contains a collection of functions in the form of program code used to build applications such as trajectory simulation using HYSPLIT, clustering using ST-DBSCAN, and K-Means algorithms. The file ui.r contains a collection of functions in the form of program code that describes attributes in the interface to be displayed.

3. Result and Discussion

3.1. System Requirement Analysis

The proposed system has two major tasks: the HYSPLIT model simulation process and cluster analysis, whereby the system can perform those tasks simultaneously. In the simulation process, the system requires hotspot sequence data and weekly GDAS meteorological data with a grid area of 1 degree. The programming language used is R, with some support packages. The package used in system development is Shiny themes for the interface [17]. The database was built using DBMS PostgreSQL, and it is connected with R programming using the PostgreSQL package. In the trajectory simulation, the system requires the SplitR package, which was obtained at Github [18]. This study uses HYSPLIT software version 4.9 in the simulation process to generate the pollutants concentration dataset. The simulation results are then stored in the database.

In cluster analysis, the system performs two clustering stages. The first clustering uses the ST-DBSCAN algorithm based on the trajectory data's spatial and temporal density. The second clustering is conducted using the K-Means algorithm on CO and CO_2 pollutant concentration as the clustering results. The system development utilizes the package fpc, which includes ST-DBSCAN implementation functions and the K-Means clustering package stats. This study adopts and modifies the architecture of the application proposed by adding a temporal aspect of the data in the clustering process [19]. In addition, the system uses the package psych to perform descriptive statistical calculations of clusters based on the observed variables. Descriptive statistics of the clusters are average, standard deviation, median, minimum, maximum, and skew.

The system uses Google Maps with several base maps to visualize simulation results and cluster analysis. Visualization using Google Maps provides a more dynamic view than those using HYSPLIT. The package used in the visualization of simulation results and cluster analysis is Leaflet. Maps are more dynamic by being able to zoom in and zoom out, providing information about simulated data points and clusters using popups, providing simulation time, map scaling, displaying icons for each starting point of the simulation, and a windward direction.

3.2. System Planning

The web-based application development was implemented using the Shiny framework in the R programming language. The system implementation includes haze dispersion simulation and visualization using the HYSPLIT model, clustering using the ST-DBSCAN and the K-Means algorithm, and mapping simulation and clustering results into Google Maps. The steps in system development are given in Figure 1.

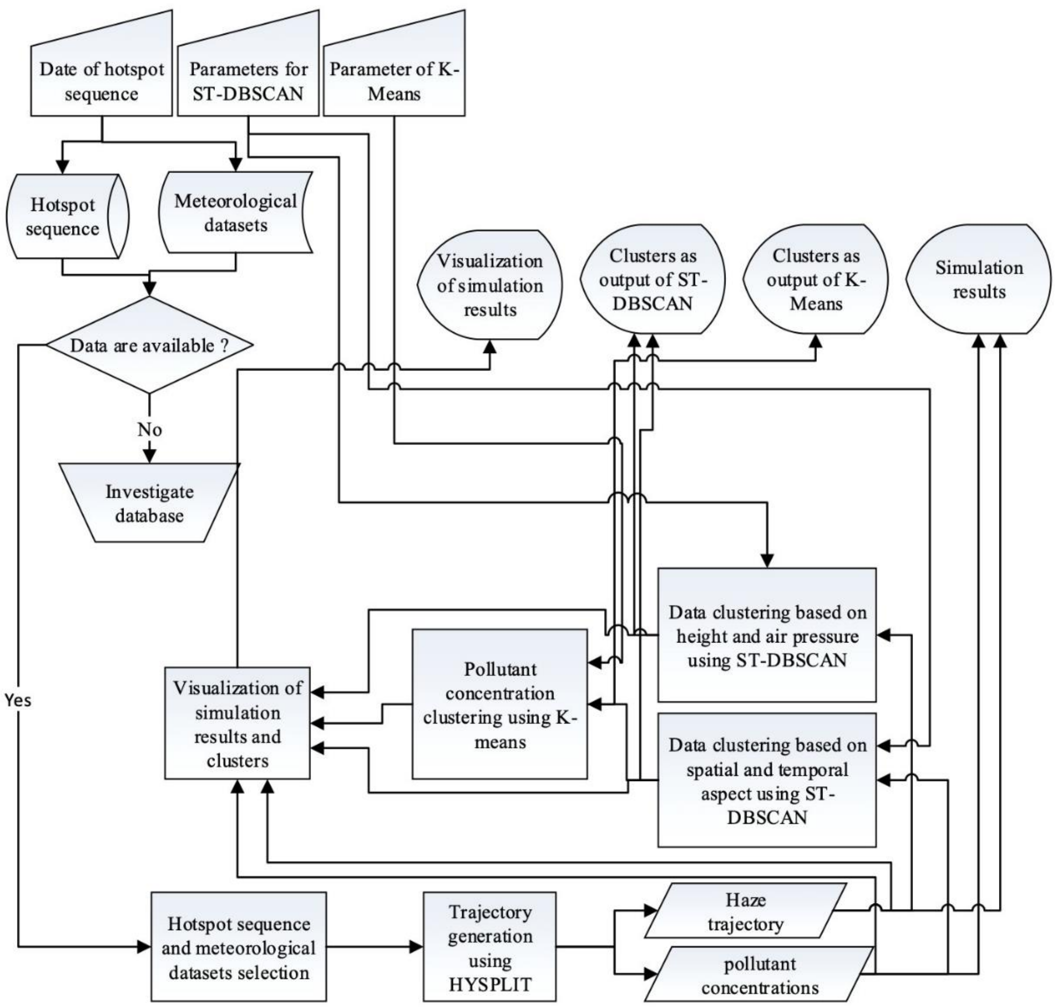


Figure 1. Steps in the system development

In the first step, the system requires the date of hotspot sequences for retrieving hotspot sequence data and weekly GDAS meteorological data on the database. Before the simulation started, the system investigated the availability of hotspot sequence data and weekly GDAS meteorological data on the database. If data are available on the database, then the data are selected according to the hotspot sequence period. If the data are not available, then users are required to download the datasets. Once the datasets were found in the database, the system simulated the HYSPLIT model for generating haze trajectory data using the SplitR package. In addition, the system performs HYSPLIT simulations for generating pollutant concentration data using HYSPLIT version 4.9. The outputs are then stored in the database, and it will be accessed for further processing. The output of the simulation is then mapped into google maps using the package leaflet in which the packages ggplot2, maptools, rgeos, rworldmap and svglite support the package. There are four base maps applied to the system: "OpenStreetMap", "CartoDB.DarkMatter", "CartoDB. Positron", and "Esri.WorldTerrain". Each data point on the map is assigned to a popup as the tool that provides the point's coordinate position, date of generated point, and other attributes of the point.

In addition to visualization on Google Maps, simulation results are presented in tabular form. The tables display all attributes of each data point as a result of the simulation. All those points of haze trajectory are then grouped using the ST-DBSCAN based on their temporal and spatial aspects. The ST-DBSCAN clustering requires input parameters epsilon 1, epsilon 2, and minimum points. Haze trajectory clusters are then mapped into Google Maps, whereas the descriptive statistics of clusters are presented in the table. Clusters containing haze trajectory and pollutant concentration as the results of ST-DBSCAN are further analyzed using the K-Means clustering. To perform this task, the system requires the input parameter number of the cluster. The best K-Means clustering result is selected based on the Sum Square Error of the clustering, and the result is presented on the maps and tables dashboard application.

3.3. System Implementation

The trajectory pattern mining application consists of two main files: server and interface. The server file, server.r, consists of a set of functions for simulation, clustering, and visualization. The interface file, ui.r, contains commands to set parameters and display the interface in the web browser.

The hotspot sequence and meteorological data database is built using the DBMS PostgreSQL 9.6, and it is integrated into the application using the PostgreSQL package. In addition to the data as input for the simulation, the database also stores simulation results of pollutant concentration, which have the attributes including haze location and time, CO, and CO_2 pollutant levels. The simulation parameters used are the initial height of 10L AGL (considering burning vegetation is trees), hotspot sequence data as the initial point of the simulation, the maximum height of 10,000 m AGL (considering the troposphere layer), and the simulation period of 72 hours.

Trajectory pattern mining application has three menus: simulation of haze trajectory, simulation of pollutant concentration, haze and pollutant concentration visualization. The Haze Trajectory menu has two sub-menus: Simulation and Cluster. The sub-menu Simulation is used to perform trajectory simulation that is run according to the date of the hotspot sequence. Figure 2 shows the results visualization on Google Maps, completed by several map navigation tools such as direction, zoom in, zoom out, legend, and map scale. An example of trajectory simulation output is provided in Figure 3. The sub-menu Cluster on the Haze Trajectory menu is used for ST-DBSCAN clustering with the user-defined parameters epsilon 1, epsilon 2, and minimum points. The results of this sub-menu are presented on Google Maps, as shown in Figure 4, and descriptive statistics tables.

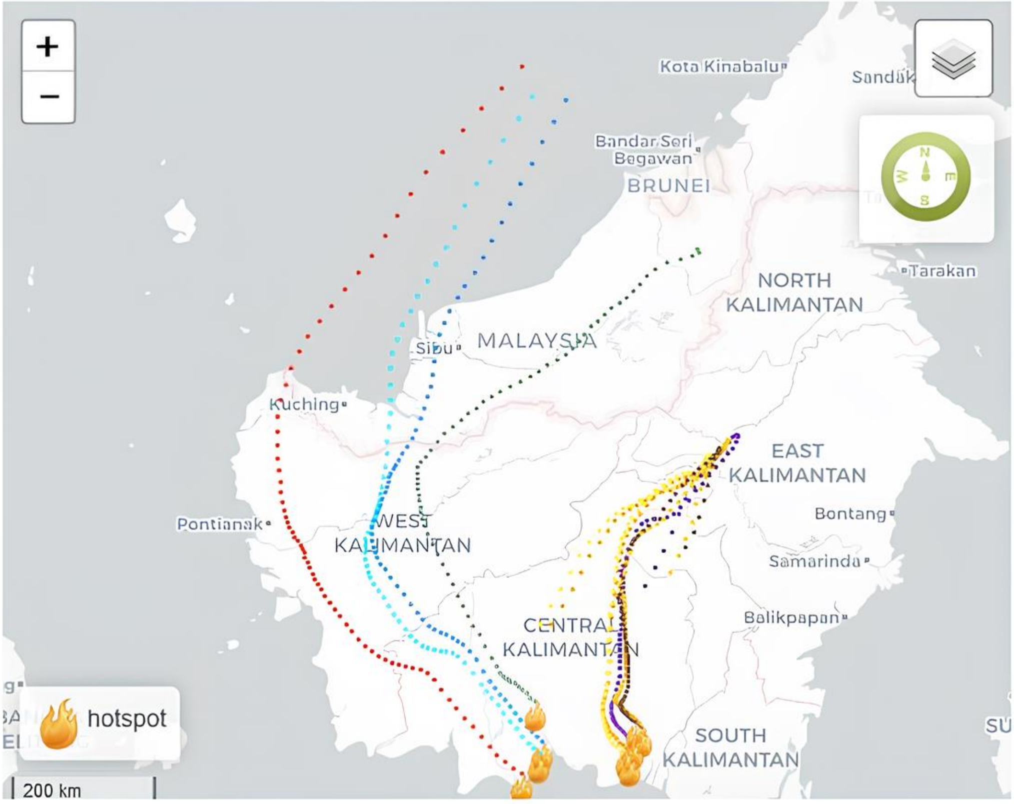
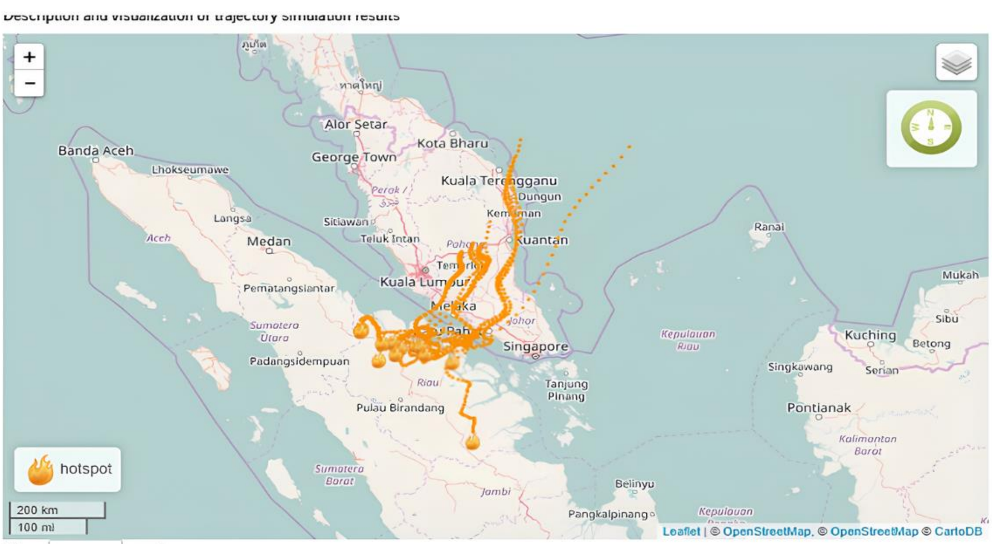


Figure 2. Haze trajectory visualization on Google map



Show 10 entries

receptor	year	month	day	hour	hour.inc	lat	lon	height	pressure	date2
1	15	7	9	0	0	2.080	100.450	10.0	1006.4	2015-07-09 00:00:00
1	15	7	9	1	1	2.101	100.481	4.5	1006.7	2015-07-09 01:00:00

Figure 3. Example of haze Trajectory simulation result

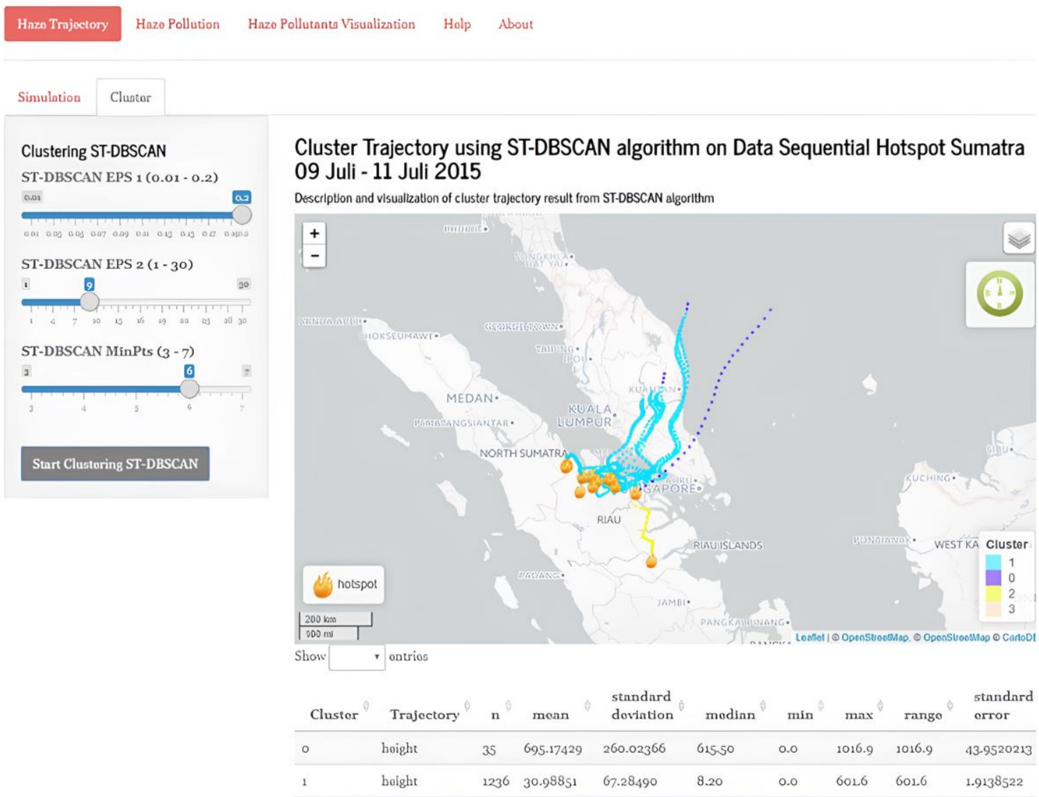


Figure 4. Output of sub-menu Cluster on the menu Haze Trajectory

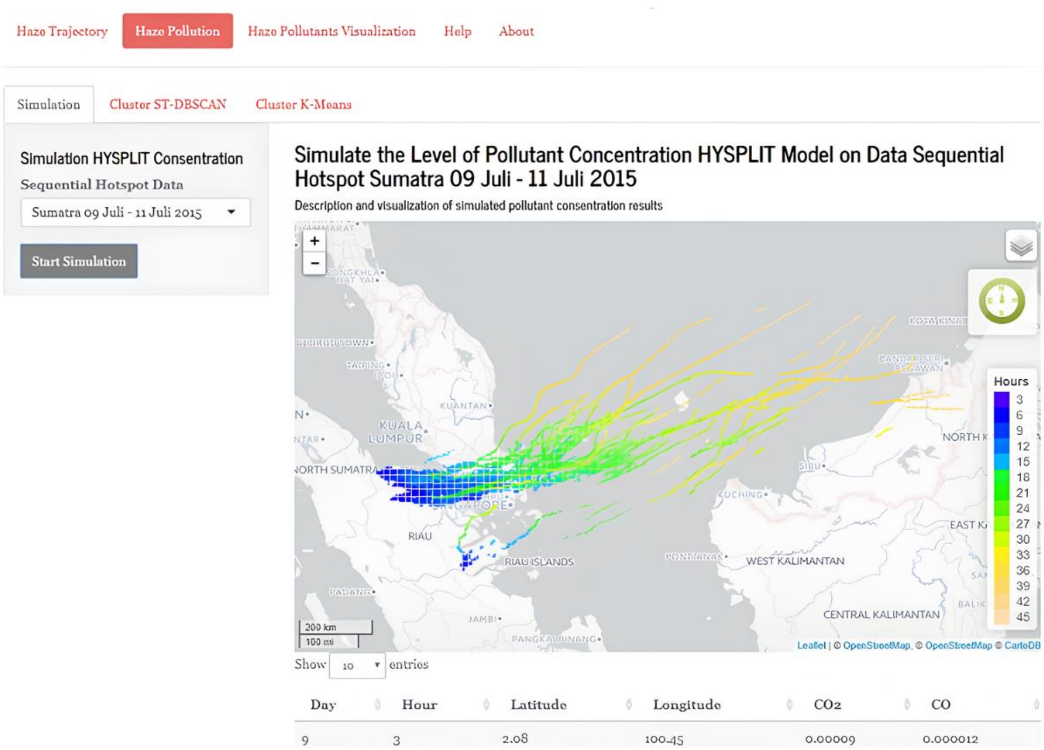


Figure 5. The output of sub-menu Simulation on the menu Haze Pollutions

The Haze Pollutants menu has 3 sub-menus: Simulation, Cluster ST-DBSCAN, and Cluster K-Means. The sub-menu Simulation simulates the pollutant concentration level based on the hotspot sequence period. The results are presented in maps and tables. Figure 5 shows an example of the sub-menu Simulation. The sub-menu Cluster ST-DBSCAN on the Haze Pollutant menu is used for data clustering based on spatial and temporal aspects. Figure 6 shows an example of the sub-menu Cluster ST-DBSCAN.

The sub-menu cluster K-Means on the menu Haze Pollutant is used for K-Means clustering on the results of ST-DBSCAN. The attributes of the data to be clustered are concentration levels of CO and CO_2. The results are also visualized on Google Maps and Spreadsheet table format. The cluster of pollutant concentration levels resulting from the K-Means clustering can be seen in Figure 7.

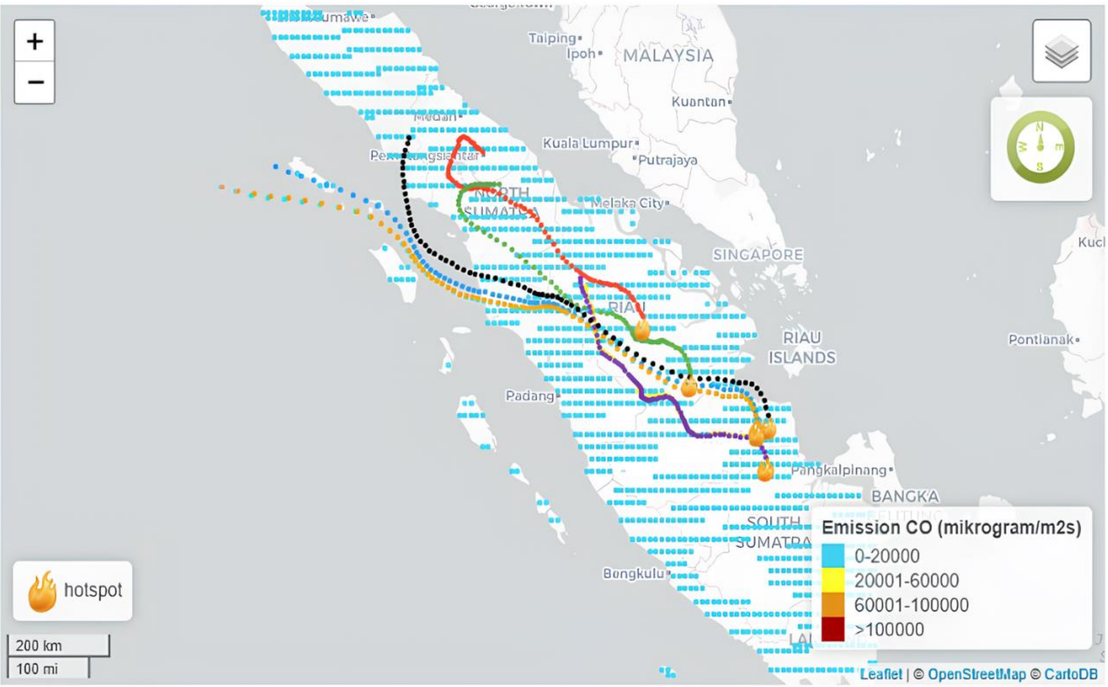


Figure 6. The output of the sub-menu cluster ST-DBSCAN on the menu Haze Pollution

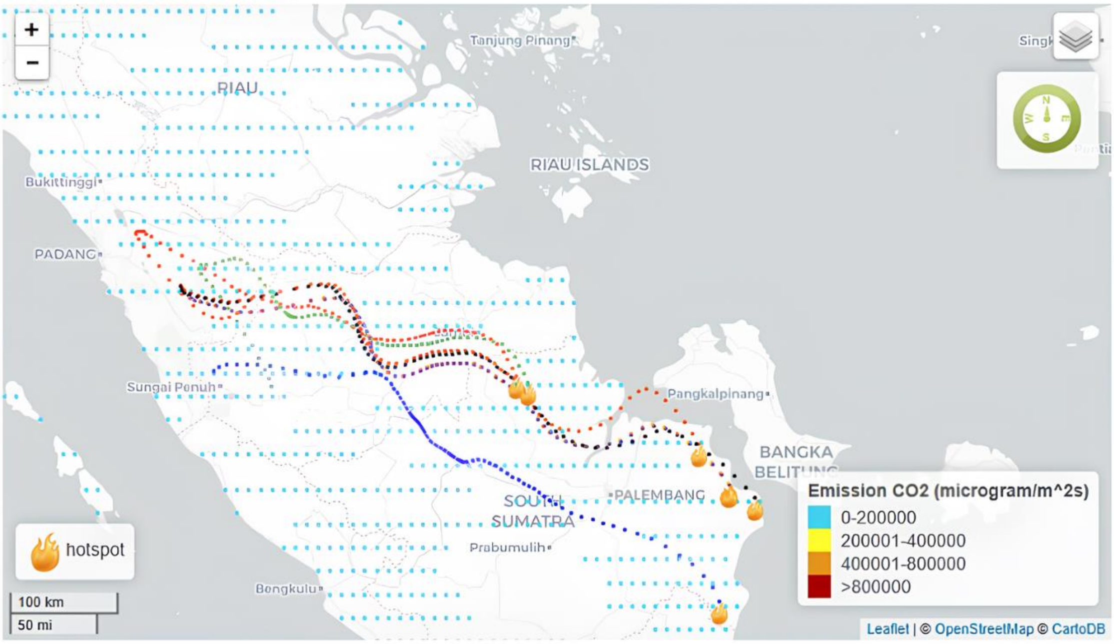
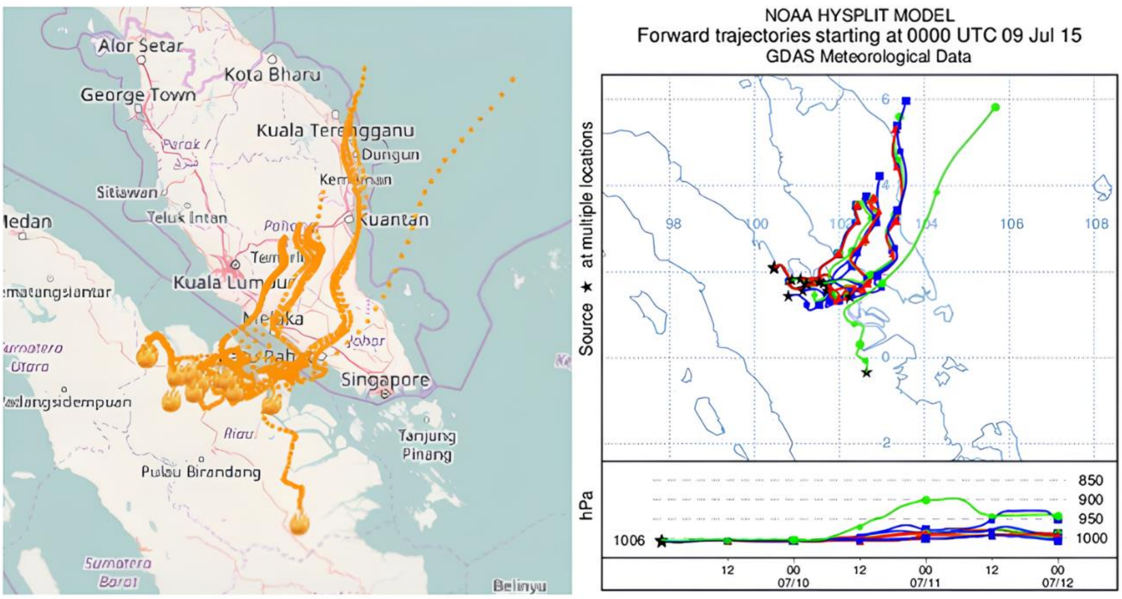


Figure 7. Output of the sub menu cluster K-Means on the menu Haze Pollution

3.4. System Testing

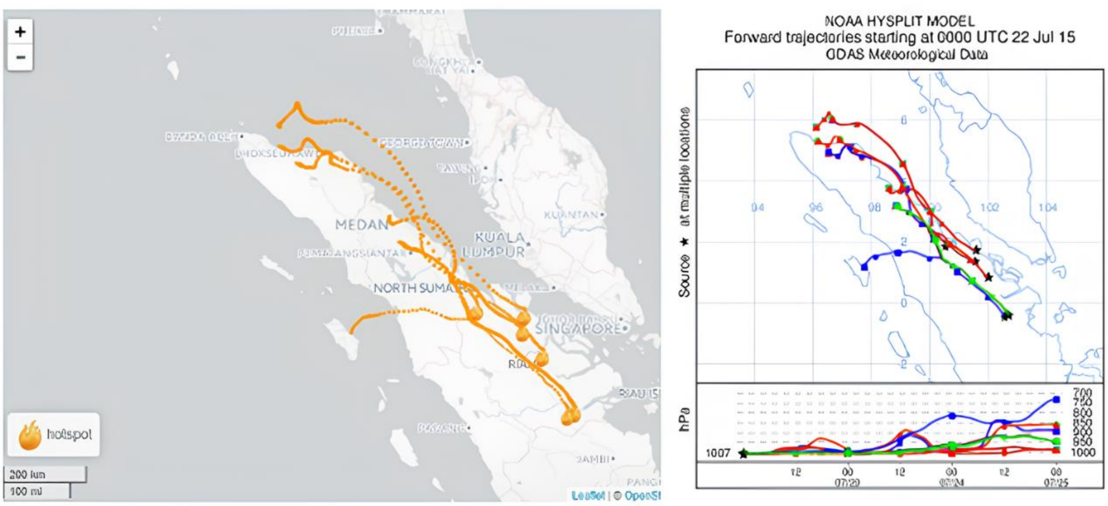
The haze trajectory pattern mining application has been tested by comparing the system's output to the simulation output using HYSPLIT. Figures 8 to 12 compare output results from the proposed system and HYSPLIT version 4.9. Testing results show that the application provides 100% accurate results of haze trajectory from peatland fires.

The system was built to simulate the direction of the haze of forest and land fires in Indonesia. The system can perform simulations with the same output as HYSPIT version 4.9, making it easy for users to simulate by determining the simulation point and date without preparing the required model parameters and data. This system produces output with more dynamic details and maps without losing information from the HYSPIT version 4.9 model. The existence of descriptive and clustering analysis in the system also provides additional information currently not offered by HYSPIT version 4.9.



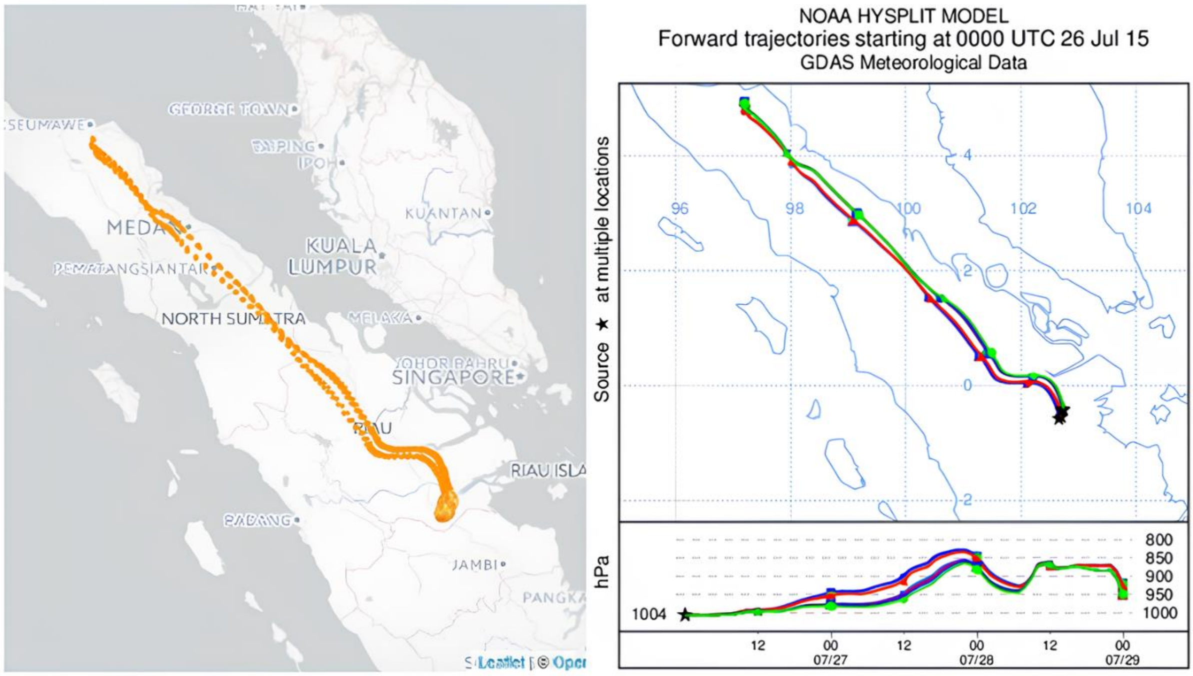
(a) (b)

Figure 8. Haze trajectory in the period of 09-11 July 2015 (a) output of Trajectory Pattern Mining and (b) output of HYSPLIT version 4.9



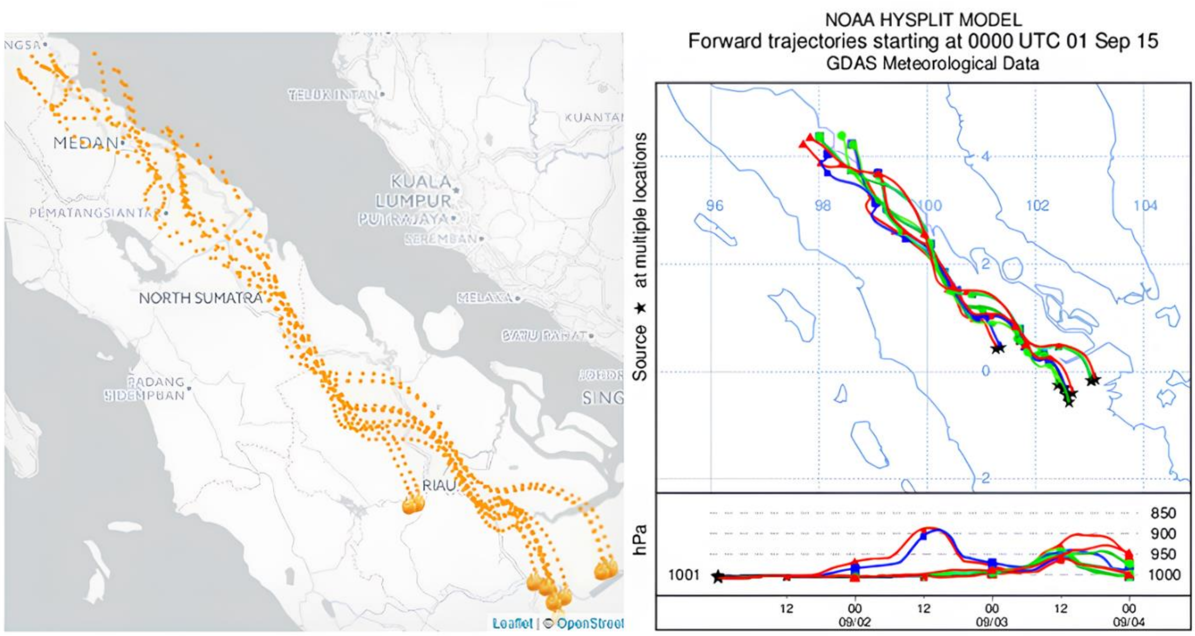
(a) (b)

Figure 9. Haze trajectory in the period of 22-23 July 2015 (a) output of Trajectory Pattern Mining and (b) output of HYSPLIT version 4.9



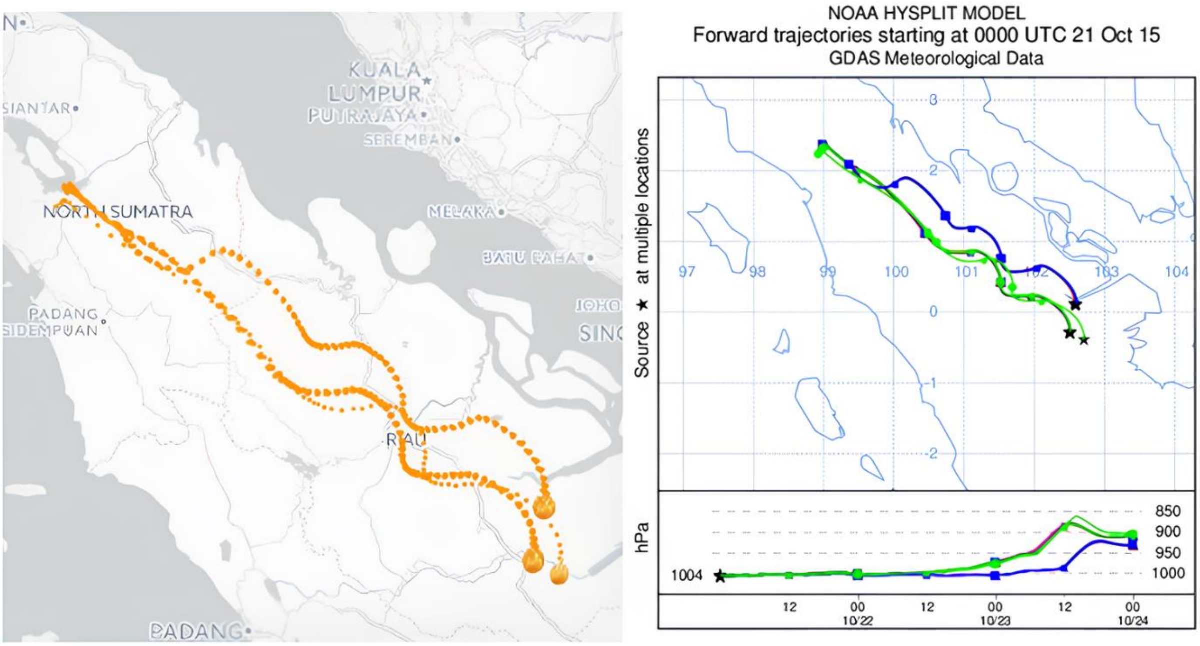
(a) (b)

Figure 10. Haze trajectory in the period of 26-29 July 2015 (a) output of Trajectory Pattern Mining and (b) output of HYSPLIT version 4.9



(a) (b)

Figure 11. Haze trajectory in the period of 01-02 September 2015 (a) output of Trajectory Pattern Mining and (b) output of HYSPLIT version 4.9



(a) (b)

Figure 12. Haze trajectory in the period of 21-22 October 2015 (a) output of Trajectory Pattern Mining and (b) output of HYSPLIT version 4.9

The system has not integrated into the real-time data source for simulation. Therefore, real-time trajectory cannot be generated in the system. The system will be improved in future work by providing real-time hotspots as initial points of simulations and meteorological data to result in real-time haze trajectory from forest and land fires.

4. Conclusions

The haze trajectory pattern mining application was successfully developed using the web-based framework, Framework Shiny. The application has three menus: Haze Trajectory, Haze Pollution, and Haze Pollution Visualization. The application has three main functions: haze trajectory generation using the HYSPLIT model, data clustering, and cluster visualization in tabular format and maps. Data clustering is performed in two stages. The first clustering uses the ST-DBSCAN algorithm to group haze trajectory data based on spatial and temporal aspects. The second clustering applied the K-Means algorithm to cluster pollutant concentration of haze trajectory resulting from ST-DBSCAN clustering. The application has been tested by comparing the output to the result of simulation using the HYSPLIT version 4.9. The results indicate that the proposed haze trajectory application successfully provided accurate haze dispersion results from peatland fires in Sumatra in 2015. A real-time application of haze trajectory from forest and land fires will be developed as future work.

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