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HYBRID SINGLE PARTICLE SIMULATION OF ATMOSPHERIC POLLUTANTS OVER BUNGOMA COUNTY IN KENYA

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Abstract
Microscale dispersion models with different levels of complexity may be used to assess urban air quality and support decision making for pollution control. Mathematical models calculate pollutant concentrations by solving either analytically a simplified set of parametric equations or numerically a set of differential equations that describe in detail wind flow and pollutant dispersion. Air pollution has been evident at Webuye town in Bungoma Kenya and this may be attributable to the current and residual effect of the pan paper and heavy chemical processing plants. A Lagrangian trajectory modeling system for urban air pollution was used to model the flow of atmospheric pollutants in Bungoma County with emphasis to Webuye, an industrial town within the County. Results of the study reveal that pollutants from the area of study exhibit a seasonal dispersion trend over Lake Victoria and surroundings to the Eastern part of Uganda. An investigation of factors that influence this trend is recommended.

Key Words: *Webuye, Kenya, HYSPLIT, Lagrangian, Eularian, Pollution*

Introduction

Air pollution due to atmospheric pollutants has been identified as the causes of poor health climate modification. According to Stein *et al*. (2015), trajectories can be used to investigate atmospheric flow patterns over an area of study. Research by McGowan and Clark (2008), used forward trajectories to locate the flow of dust from the source lake to areas several kilometers away. Ben-Ami *et al*. (2015) carried out a study using a dispersion model to investigate the flow of North American dust from the Bodélé depression to neighboring regions. The findings of the research revealed that the dust affected kilometers of regions form the source. Studies by Bhattachan *et al*. (2012) revealed that dust from southern Kalahari Desert was moving into the Nile along a forward trajectory. An investigation conducted by Ongoma *et al*. (2014) to ascertain the transport and dispersion of total suspended particles over Nairobi city revealed that the pollutant was dispersed more than 100 km from the city and reduced concentrations of the same in the city. A similar study was also carried by Muthama *et al*. (2015) and indicated that transportation of pollutants took place to several kilome ters away from a coal mining plant along trajectories. Studies by Kiano *et al*. (2018); Achoka (2012) have indicated pollution over the area of study with potential health effects. There is however minimum literature on mathematical modeling of the transport of pollutants over this area of study. The aim of this study was to simulate the flow of pollutants over Bungoma County in Kenya with emphasis on Webuye Town. The Town is characterized by chemical manufacturing industries and therefore, a subject of research interest in air pollution. The main objective of this study was to determine the dominant wind direction during selected seasons and corresponding flow of pollutants over the area of study.

Methodology

Area of Study

Webuye is an industrial town in Bungoma County, Kenya characterized by a tropical climate, and subsistence agriculture. The area of study is home to previously, the largest paper processing company in East and Central Africa (pan paper mills) alongside East Africa heavy chemicals (currently registered as Panpaper Chemicals) The residual effect of pollutants from the former (which is partially working) and current pollution of the later can be source of pollutants that will be transported and dispersed to other areas. The Latitude is 0.6166667°, Longitude 34.7666667°, average annual Temperature of 24°C / 75.2° with Elevation of 1523m. The map of study area is shown in figure 1 below. This study makes attempts to review literature on langragian modeling of pollutants and will use a hybrid single particle langrangian model to predict the flow of pollutants in Webuye Town, Bungoma County, Kenya.

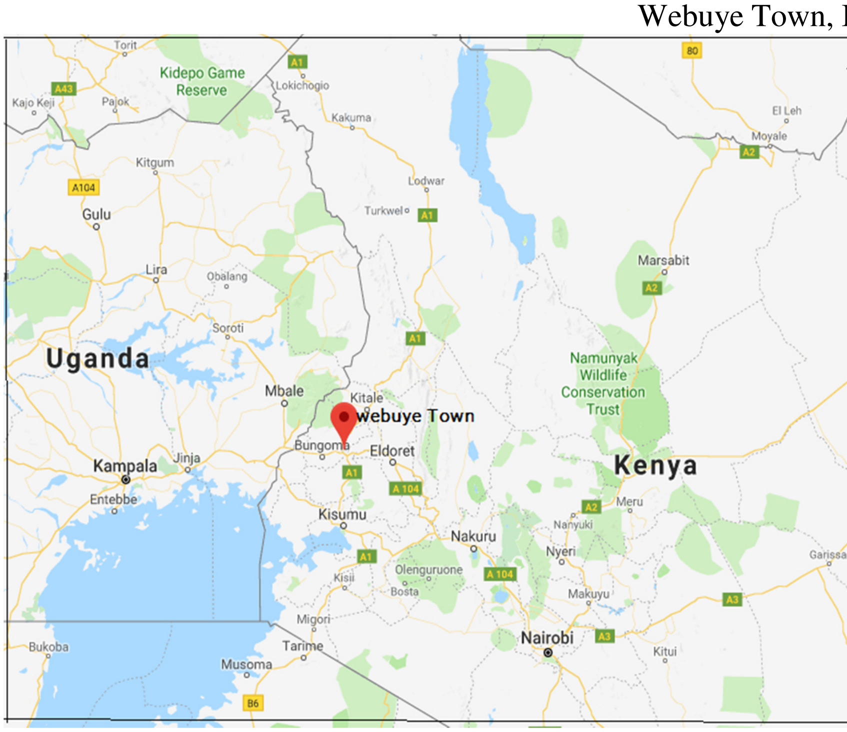

Fig. 1(a): Map of the study area (Source; [Google maps, 2018]).

Theoretical Framework

Advection can be defines as the transport of a substance by bulk motion. The substances include pollutants, enthalpy or any material that contains thermal energy. The transport is **conservative**. The fluid is the vector field and the material transported the scalar field distributed over space.

According to [10], the steady state advection-diffusion equation is given by:

$$u\frac{\delta c}{\delta x}+v\frac{\delta c}{\delta y}+w\frac{\delta c}{\delta z}=\frac{\delta}{\delta x}\left(k_x\frac{\delta c}{\delta x}\right)+\frac{\delta}{\delta y}\left(k_y\frac{\delta c}{\delta y}\right)+\frac{\delta}{\delta z}\left(k_z\frac{\delta c}{\delta z}\right)\ldots\ldots\ldots\ldots(1)$$

where c denotes the average concentration, Kx , y K , Kz and u, v, w are the Cartesian components of eddy diffusivity and wind profile, respectively and $0 < \ < h, 0 < \ < , 0 < \ <$, where h is the height of the atmospheric boundary layer and x L , y L are far away from the source; considering that eddy diffusivities and wind profile have a continuous dependence on the z variable and the x-axis of the Cartesian coordinate system aligned in the direction of the actual wind, and the y-axis oriented in the horizontal crosswind direction, and the z-axis chosen vertically upwards.

This equation can be solved using the criteria outlined by Blackadar (1997); Buske *et al*. (2009) into a 3-D analytic equation of the form given in equation (2) below:

c(x,y,z) = $\sum_{m=0}^{m}\sum_{n=0}^{n}c_{m,n}(x)Y_n(y)Z_m(z))$……………………………………………(2)

According to stein *et al*. (2015) the advection of a particle or puff is computed from the average of the three-dimensional velocity vectors at the initial-position P(t) and the first-guess position P'(t+Δt). The velocity vectors are linearly interpolated in both space and time. The first guess position is

P'(t+Δt) = P(t) + V(P,t) Δt…………………………………………………....(3)

and the final position is P(t+Δt) = P(t) + 0.5 [V(P,t) + V(P',t+Δt)] Δt……………(4)

HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) uses an integrated (Hybrid of) lagrangian and eularian approaches as outlined by stein *et al*. (2015).The eulerian langrangian approaches are defined in Ashrafi *et al*. (2014). According to Anurag (2004), paper and pulp can be sources of pollutants that can be transported as suspensions along other particles like dust. Studies by Ongoma *et al*. (2014) revealed that atmospheric dispersion over an area of study exhibits seasonal characteristics across major seasons namely December-January-February (DJF); March-April-May (MAM); June-July-August (JJA) and September-October-November (SON) seasons respectively:

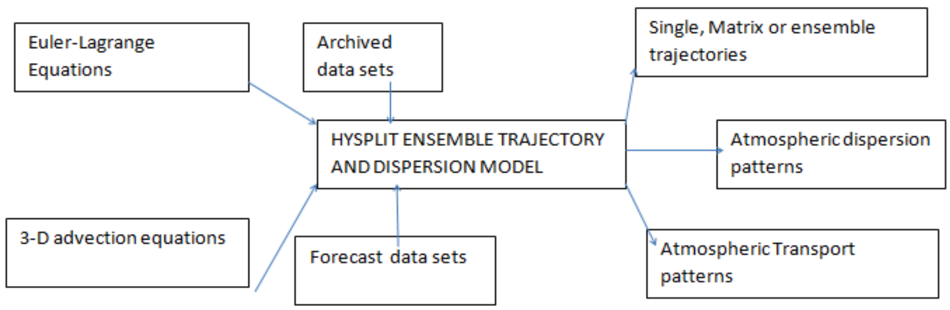

Fig. 1(b): Theoretical Framework

Simulation of Atmospheric Pollutants

HYSPLIT was used according to the criteria outlined by Ashrafi *et al*. (2014). Normal trajectory was computed from the Global Data Assimilation System (GDAS) archive at a resolution of single degree spanning 2006 to present at source location 0°36'14.3"N; 34°46'22.4"E corresponding to the area of study using a 7-day archived meteorological file at 1506 meters above sea level. Forward and Backward trajectories were generated. Wind roses were plotted using gridded model data for the location within the meteorological model domain. A single Wind rose showed the frequency of wind direction at a single location on a 16-point compass. In addition, rings were plotted that represent the wind speed frequency for wind speed classes.

Results and Discussion

Wind Frequency and Direction

Figure 2 below shows a wind rose over the area of study

Results of this figure reveal that the dominant winds over the area of study are North Easterlies during DJF and SON seasons and South Easterlies during MAM season respectively. Low frequency North Easterly and South Easterly winds are evident during the JJA season. In general; the winds are majorly low frequency winds of maximum 4 meters per second.

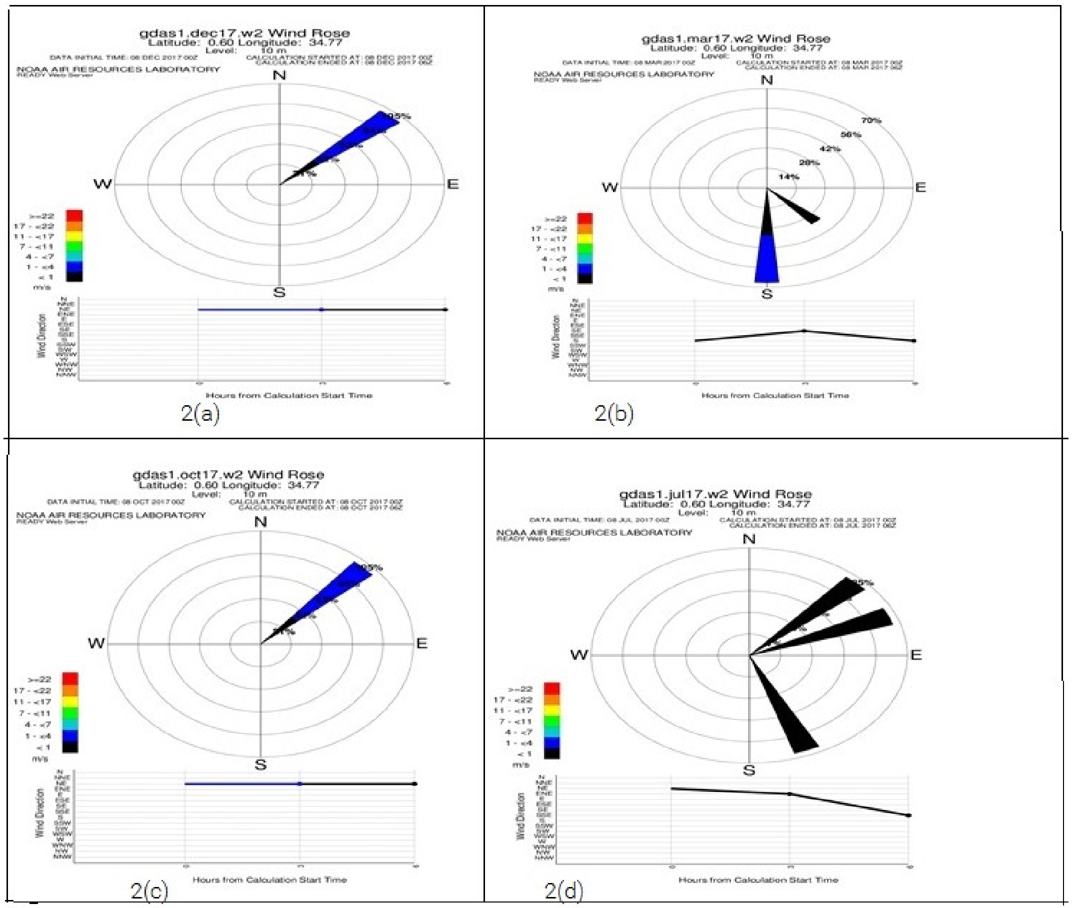

Fig. 2(a-d): Windrose of Webuye Town for selected months in DJF (2a); MAM (2b); SON (2c) and JJA (2d) seasons.

Forward Trajectories Over the area of Study

Figure 3(a) to 3(d) below shows forward trajectories over selected months in DJF, MAM, SON and JJA respectively.

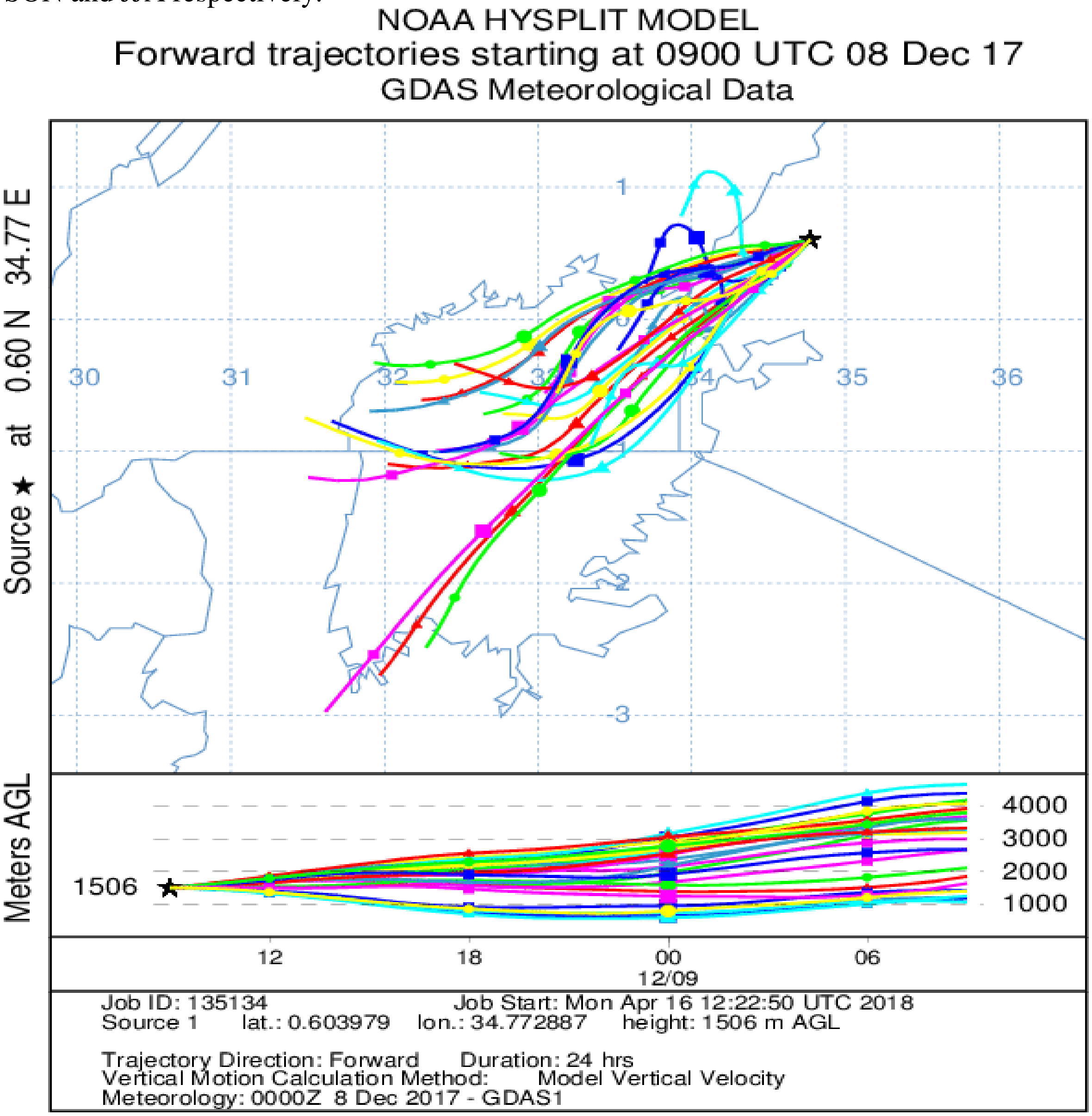

Fig. 3(a): Forward trajectory during a month in the DJF season over Webuye town

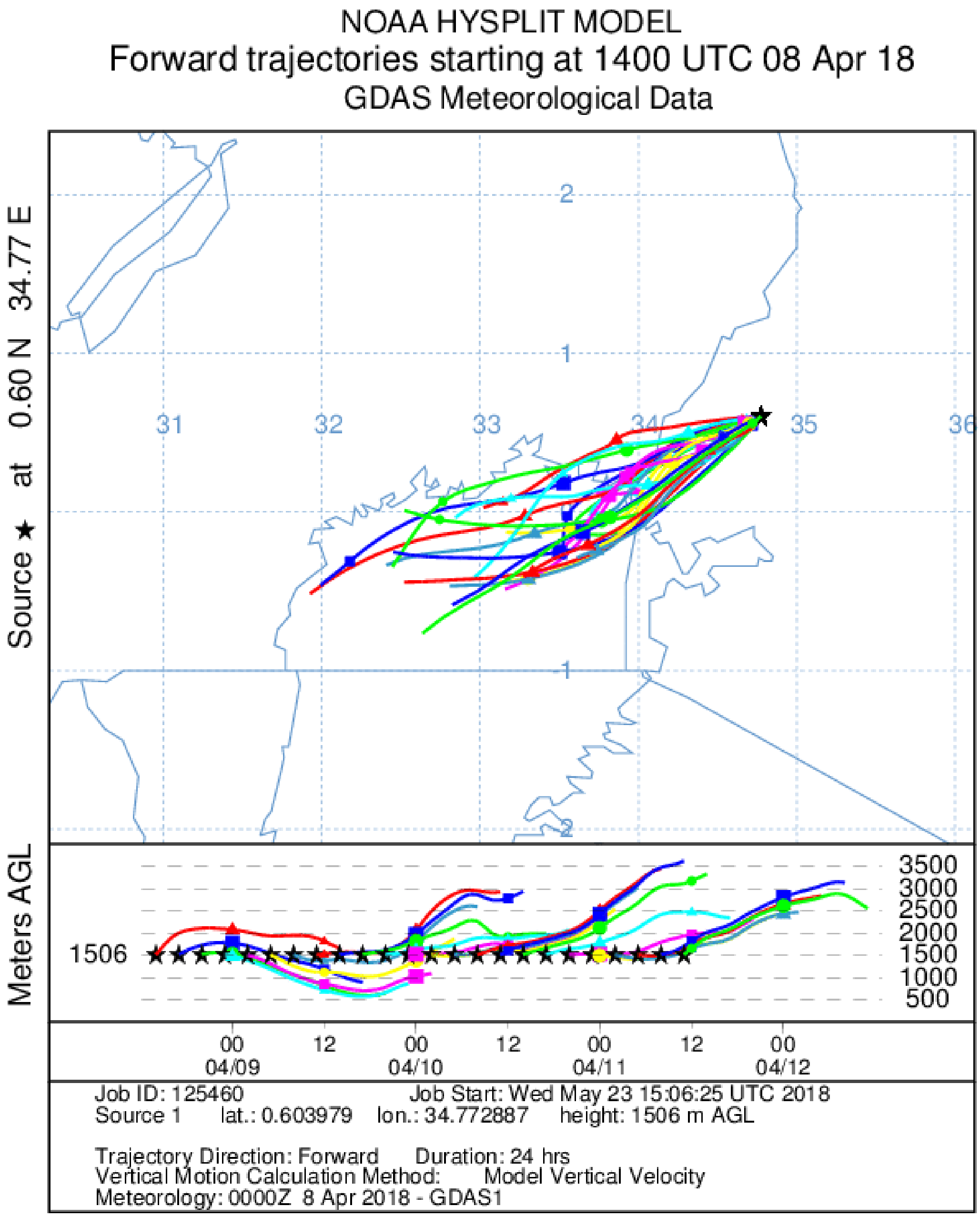

Fig. 3(b): Forward trajectory during a month in the MAM season over Webuye town

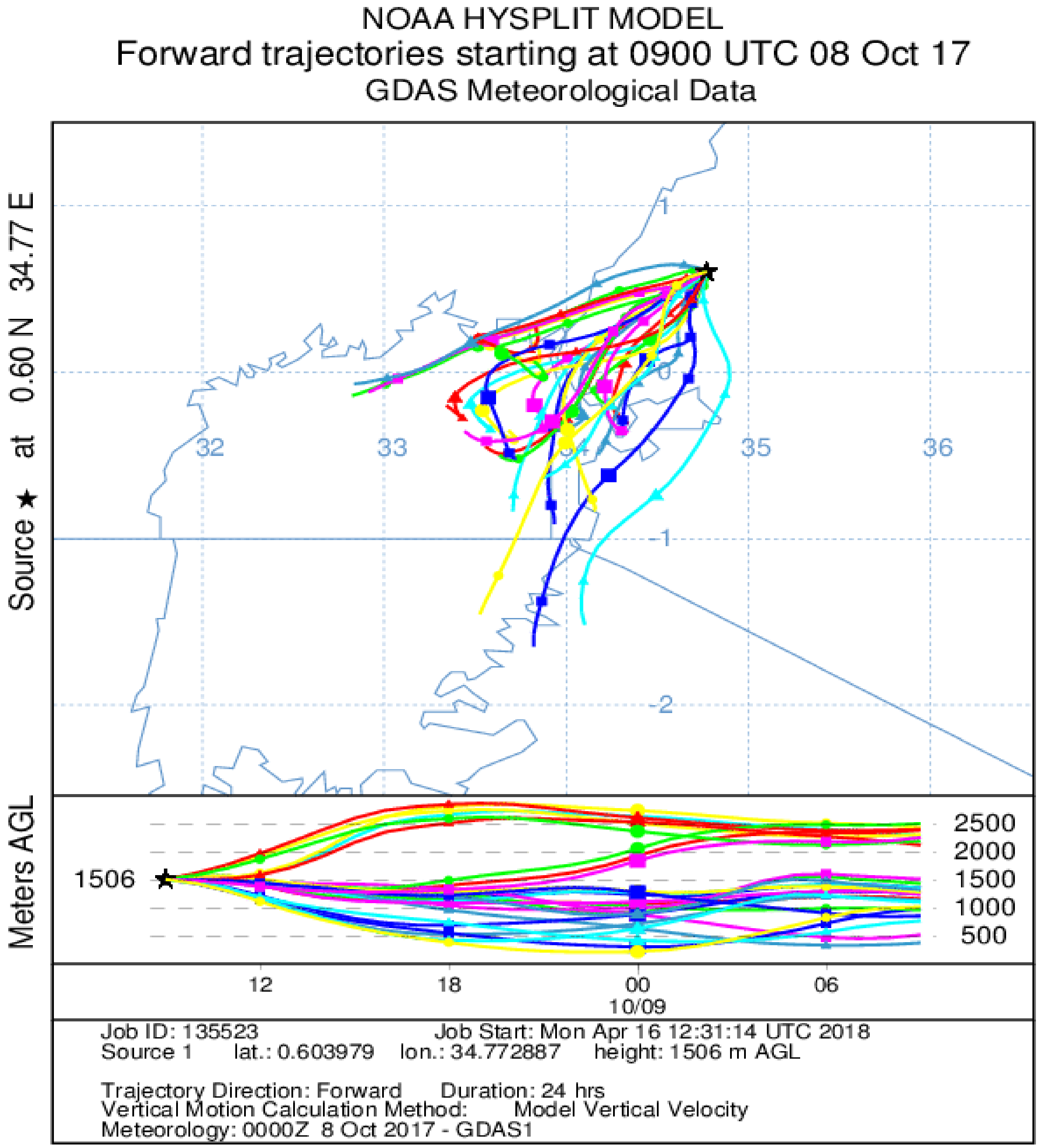

Fig. 3(c): Forward trajectory during a month in the SON season over Webuye town

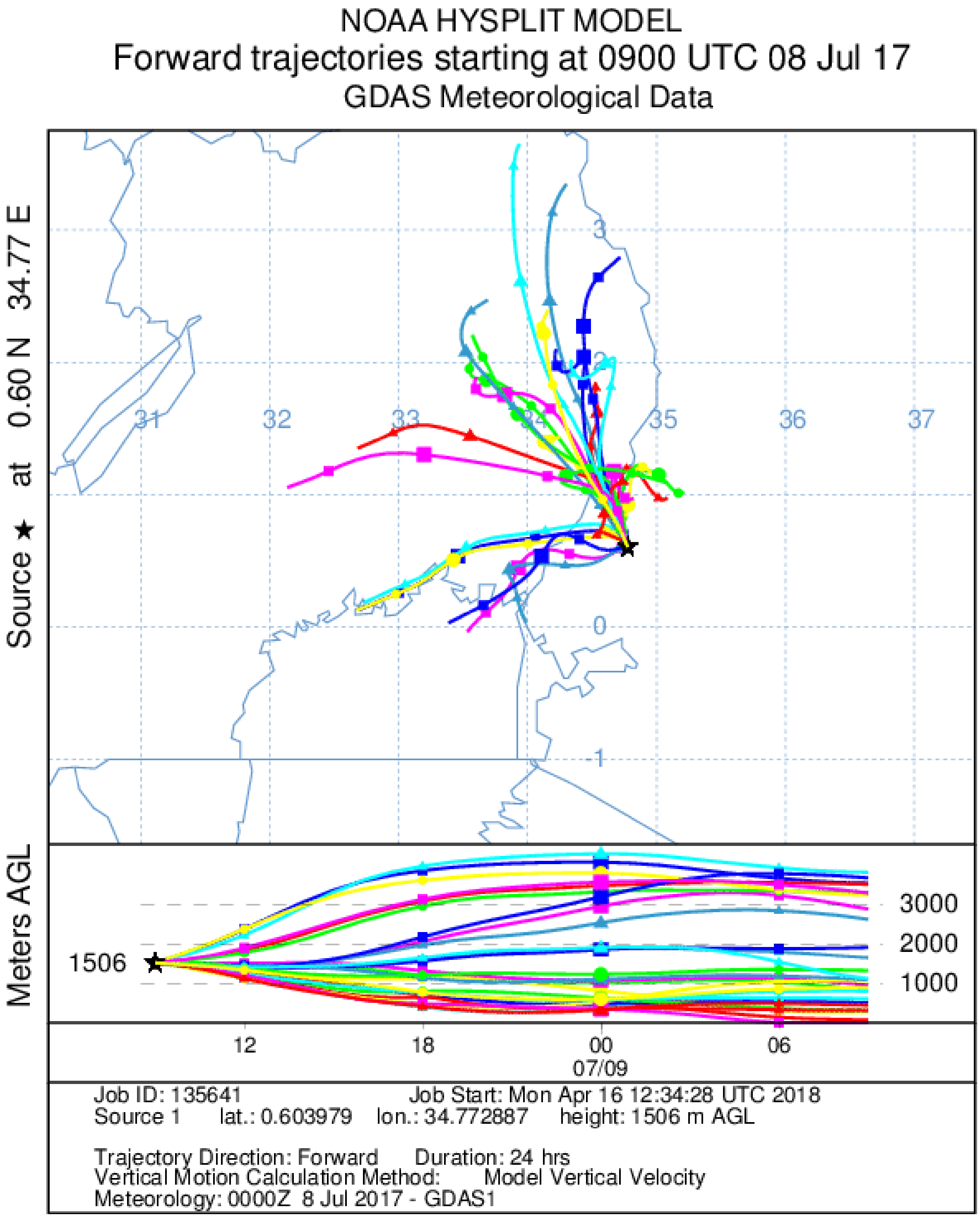

Fig. 3(d): Forward trajectory during a month in the JJA season over Webuye town

The results show that transport of pollutants from Webuye town takes a south westerly direction except in MAM season; where the flow of pollutants is both South and North westerly. Since the wind roses over the area of study reveal majorly North Easterly winds dominance in all seasons except in the MAM season, there is a possibility that transport of pollutants over the area of study is influenced by either convergence of winds or Congo air mass respectively. In the former, the zonal component of the intertropical convergence Zone (ITCZ) formed by convergence of North Easterly and south easterly trade winds can influence pollutant flow across SON, DJF and MAM seasons Ininda (1995).The results show that pollutants from the area of study are dispersed into Lake Victoria and surroundings to heights of up to 2500-3000 meters above ground level. The results also show that pollutants from webuye town are dispersed into Eastern Uganda during the JJA season.

Conclusion and Recommendation

The presence of industries in webuye town can be sources of air pollution whose Impact is both local and trans-boundary. This study used a hybrid single particle Lagrangian model to investigate the flow of pollutants over webuye Town in Bungoma County of western Kenya. Results of the findings revealed that both current and residual pollutants are dispersed across webuye town to Lake Victoria and environs. It was also observed that pollutants were dispersed up to 3000 meters above sea level and up to the terrestrial Eastern Uganda during the JJA season.An investigation of factors that influence this trend is recommended.

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