Department of Meteorology

University of Nairobi

Laboratory Manual

Micrometeorology and Air pollution

SMR 407

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Signature **Date**

December 2014 Version

Lab 1: Introduction to the operations of HYSPLIT model

Objectives:

To establish familiarity with the basic operations of the HYSPLIT model.

Background:

The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is a system for computing simple air parcel trajectories to complex dispersion and deposition simulations.

The model is a freeware and can be run interactively on the Web through the READY system on our site or the code executable and meteorological data can be downloaded to a Windows PC. The registered PC version is complete with no computational restrictions, except that user's must obtain their own meteorological data files. The unregistered version is identical to the registered version except that it will not work with forecast meteorology data files.

Please consult the background information of the model.

[**NOTE:** Please carry and reconcile units through all of your calculations. Submit all your work in soft form by the end of the week]

Instructions:

Using the unregistered version of the web based HYPLIT:

1. Access the Model description information and discuss the two broad functions of the model
2. Access the archive data and describe the meteorological input data used by the model
3. Create plot for the following fields: relative humidity (2m); mixed layer height; and sensible heat flux. Discuss the spatial pattern of plots. N.B Use 2D maps (NCAR Graphics)
4. Perform a stability analysis over Nairobi for a date in the month of October 2014. Use the default settings. Discuss the results

Lab 2: MONITORING AND ANALYSING SURFACE CO AND OZONE

Objective: To familiarize with a meteorological instrument used for air pollution monitoring.

INSTRUCTIONS:

1. Using the carbon monoxide and <u>ozone analyzers</u>, <u>take and record</u> in a table 4 (ppb/volume) the amount of CO and ozone at intervals of 5 minutes. Repeat these 11 times to obtain 12 sets of readings.

Table 1:

Time	Carbon Monoxide (ppb/v)				Ozone (ppb/v)			
	Reading 1	Reading 2		Average	Reading 1	Reading 2	Reading 3	Average
e.g. 10.00-10.02	380	380		279	380	381	279	380

2. Using the data in table 4 above, plot the CO and Ozone with time.

3. Using the data provided in Table 5 below, compute the half-hour amount of carbon monoxide and ozone.

4. Plot the half hourly Reynolds decomposition components of carbon monoxide and ozone versus time

5. Discuss the plots obtained in 2 and 4 above. Save your work in a folder

Table 2: Carbon monoxide and ozone data at Chiromo campus station for (give date) using ** analyser

Time	Carbon Monoxide (ppb/v)	Ozone (ppb/v)

Lab 3: The wind profile and turbulent transport

Objectives:

To establish familiarity with the form of the wind profile and the means of calculating the surface roughness length. To provide practice in plotting frequency wind rose using Excel.

Background:

Please consult the attached notes as background information to this lab.

Assignment:

[**NOTE:** Please carry and reconcile units through all of your calculations.]

1. It is a windy, cloudy day over an extensive suburban area. Given the following observations of wind speed at different heights above the surface:

z (m)	10	15	25	45	85
$\overline{u}$ (m s^{-1})	8.40	9.45	10.80	12.30	14.00

and assuming the von Kármán constant (k) is 0.40, the air density $\rho = 1.2 kgm^{-3}$, and neutral stability, answer the following questions:

(a) Plot $\overline{u}$ versus ln(*z*).
(b) Using your graph, determine the roughness length, z_0 (m).
(c) Using the Power Law by Dean and wind data for z =10m, Calculate new $\overline{u}$ to 2 significant figures. Plot $\overline{u}$ versus the new ln(*z*), and determine the new roughness length, z_0 (m).
(d) Compare the values of z_0 determined from both approaches.
(e) Using the log-law wind profile and z_0, computed using PL-D, determine the friction velocity, u_* (m s^{-1}).

2. Tabulated below is wind data measured over an urban station.

	Frequency of wind speed (Knots)				
	2-3	**4-7**	**8-12**	**19-24**	
N	3	4	8	4	19
NE	4	10	3	2	19
E	8	8	2	2	20
SE	4	4	7	3	18
S	2	4	3	2	11
SE	3	3	2	2	10
W	12	10	27	5	54
NW	6	17	10	5	38
Totals	42	60	62	25	189

(a) Plot the Frequency wind rose for the above wind data using EXCEL.

(b) Discuss the observed wind pattern and its implications on air pollution over the given urban area.

Lab Notes

The Power Law by Dean is given by

$$\frac{u}{u_1} = \left(\frac{z}{z_1}\right)^p \qquad \textbf{(1)}$$

Where $p = \frac{n}{2-n}$

Stability condition	**n**
Large lapse rate	0.20
Zero or small lapse rate	0.25
Moderate inversion	0.33
Large inversion	0.50

3.2 The logarithmic wind profile

Consider first the simplest case of the wind profile in a neutral surface layer. In this situation the temperature variables will not play an active role, as indicated by the fact that the Richardson number will be small (indicating that shear production of turbulence is much larger than buoyant production or suppression). So what is the mixing length likely to depend on? It turns out that it is dependent *only* on distance from the surface, *z*. Substituting $l_m = kz$ (where *k* is a dimensionless constant) into (3.2) we find that the wind shear is inversely proportional to *z*:

$$\frac{d\bar{u}}{dz} = \frac{u_*}{kz}. \qquad (2)$$

We know that wind speed must fall to zero at some height we will call z_0. Integrating this expression:

$$\int_0^{\bar{u}} d\bar{u} = \frac{u_*}{k}\int_{z_0}^{z}\frac{dz}{z}$$

yields the *log wind profile:*

$$\boxed{\bar{u} = \frac{u_*}{k}\ln\left(\frac{z}{z_0}\right)} \qquad (3)$$

As you will find in experiment 1, this is an excellent model for the wind profile near the ground in almost all conditions. In this equation

- *K*, sometimes written as κ (the Greek letter “kappa”), is *von Karman’s constant* and has a value, derived from observations, of around 0.4. It is the same for all turbulent fluids. Note that it is
- z_0 is the *roughness length*, defined as the height where the wind according to the log law falls to zero. In fact z_0 lies within the roughness sub-layer where $\bar{u}$ deviates from the log law. It represents the bulk effects of roughness elements in the surface layer and very approximately has a value around 0.1 times the height of the roughness elements.

Lab 4: Modelling of Atmospheric Dispersion

Objectives:

To use a simple Gaussian Plume Model (GPM) to understand something of the dispersion of pollutants in the atmosphere, and the limitations of these kinds of modelling techniques.

Method:

To a large extent, industrial pollutants are emitted from smoke stacks. Material emitted from a stack will disperse vertically and horizontally down wind from the stack by an amount which will depend on the state of turbulence in the air. The amount of turbulence in turn is determined to a large extent by the atmosphere's vertical stratification and stability, surface roughness, and wind speed. While the methods discussed here apply to a single smoke stack, it is not difficult to extend them to include multiple stacks, as well as area and line sources.

While the instantaneous concentration of pollutants across a plume down wind of the stack will have sharp boundaries, the mean concentration averaged over more than two hours or so, will closely follow a normal distribution. In other words, the peak concentration will be along the mean centreline of the plume, with concentrations falling off exponentially in all directions perpendicular to the centreline.

Gaussian plume models which exploit the fact that concentrations follow this normal distribution, have been developed to calculate pollutant concentrations downwind of a stack. Gaussian plume models have an advantage of being conceptually simple, and very inexpensive computationally to run - even over multi-year periods. In fact, nearly all regulatory models used by governments and industry are based on this kind of a formulation. This is despite the fact that better models exist.

The Gaussian model equation (Oke page 328):

$$\chi(x,y,z,H) = \frac{X}{2\pi\sigma_y\sigma_z}\exp\left[\frac{y^2}{2\sigma_y^2}\right]\times\left[\left(\frac{(z-H)^2}{2\sigma_z^2}\right)+\left(\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where X is the rate of emission from the source (kg s^{-1}), σ_y, σ_z are the horizontal and vertical standard deviations of the pollutant distribution in the y and z directions (m), $\bar{u}$ is the mean horizontal wind speed through the depth of the plume direction (m s^{-1}), and H is the effective stack height (m). χ is the pollutant concentration (kg m^{-3}), and is a function of space and the nature of turbulence. If only the ground level concentrations are required, this equation simplifies somewhat:

$$\chi(x,y,0,H) = \frac{X}{\pi\sigma_y\sigma_z\bar{u}}\exp\left[-\left[\frac{y^2}{2\sigma_y^2}+\frac{H^2}{2\sigma_z^2}\right]\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

The σ's are a measure of the vertical and horizontal spreading of a plume and thus represent the amount of atmospheric dispersion which depends on the state of turbulence. They will be a function of x, as well as atmospheric stability and surface roughness. The trick in much of this kind of dispersion modelling is in accurate calculation / estimation of the σ's. This is a problem similar to the accurate determination of eddy diffusivities. In this lab you will be using an empirical method to estimate the σ's based on estimates of stability and surface roughness.

In the absence of accurate turbulence data, it is possible to crudely categorize the stability of the atmosphere based on routine atmospheric observations (Table 1).

Table 1: Note: A, extremely unstable; B, moderately unstable; C, slightly unstable; D, neutral (heavy overcast day or night); E, slightly stable; F, moderately stable.

Surface	Daytime solar radiation			Nighttime conditions	
wind m s^{-1}	Strong	Moderate	Slight	$\geq$ 4/8 clouds	$\leq$ 3/8 clouds
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-4	B	B-C	C	D	E
4-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Briggs (1973) proposed a series of empirical formulae for the determination of σ_z and σ_y:

Table 2: Briggs' σ_z,σ_y formulae for elevated small releases, where $10^2 < x < 10^4$ m.

Stability	σ_y (m)	σ_z (m)
Class		
Open country conditions		
A	$0.22x(1 + 0.0001x)^{-.5}$	$.20x$
B	$0.16x(1 + 0.0001x)^{-.5}$	$.12x$
C	$0.11x(1 + 0.0001x)^{-.5}$	$.08x(1 + 0.0002x)^{-.5}$
D	$0.08x(1 + 0.0001x)^{-.5}$	$.06x(1 + 0.0015x)^{-.5}$
E	$0.06x(1 + 0.0001x)^{-.5}$	$.03x(1 + 0.0003x)^{-1}$
F	$0.04x(1 + 0.0001x)^{-.5}$	$.016x(1 + 0.0003x)^{-1}$
Urban conditions		
A-B	$0.32x(1 + 0.0004x)^{-.5}$	$.24x(1 + 0.001x)^{.5}$
C	$0.22x(1 + 0.0004x)^{-.5}$	$.20x$
D	$0.16x(1 + 0.0004x)^{-.5}$	$.14x(1 + .0003x)^{-.5}$
E-F	$0.11x(1 + 0.0004x)^{-.5}$	$.08x(1 + .00015x)^{-.5}$

Questions:

In the following questions, assume that we are talking about a proposed factory emitting 1 kg s^{-1} of some noxious pollutant.

1. Make a full log plot of σ_z vs. x for stability classes A, D, F in open country, and compare it to a plot in urban conditions. Comment on and explain the differences between stability classes and surface type.
2. Assuming neutral conditions over open country, a wind speed of 10 m s^{-1}, and a stack height of 50 m, make a surface and contour plot of the pollutant concentration at the ground between the stack and a distance 10 km down wind of the stack. Where and what is the maximum concentration?
3. What stack height would be required to reduce this maximum concentration to 50% of the above value under the same wind and stability conditions? Where is the location of the maximum? Why has it changed? Compare the pollution concentration at x = 10000 m for both stacks.

   [Hint: Repeat the second exercise of Question 2 with higher values of H (say 55, 60, 65 m, etc.) and find a situation where the maximum downwind concentration is less than half of the one for H = 50 m.]

References:

Pasquill, F., (1961). The estimation of the dispersion of windborne material. *Met. Mag.*, **90**, 33-49.

Briggs, G. A., (1973). Diffusion estimation for small emissions. Env. Res. Lab., Air Resources Atmos. Turb. and Diffusion Lab., 1973 Annual Report, ATDL-106, USDOC-NOAA.

The assignment is due on January 20, 2015

Your comments are appreciated

If you wish to make comments, fill this out and give it to the instructor, anonymously if desired.

1. Did this practical meet its objectives?
2. Did you learn something from it?
3. Were the written / verbal instructions clear?
4. Was the exercise too long?
5. Can you suggest ways of improving the practical?
6. Other comments ...