CHAPTER 2

DATA AND METHODOLOGY

> This Chapter outlines the data and the methods of analysis used. Plume structures were analysed using Lagrangian forward kinematic trajectories to calculate the yearly and seasonal transboundary transportation of aerosols in the southern African subregion. Total trajectories were analysed using the Wall analysis tool and classified according to tropospheric level and direction of transport.

The nature of data and methods used in analysis are discussed. The Climatology Research Group trajectory analysis model (D'Abreton, 1996) has been used, together with input data from the European Center of Medium Range Weather Forecasting (ECMWF). The model has proved to be accurate over the southern African region (Garstang *et al.,* 1995, Swap *et al.*, 1995). ECMWF data can therefore be used with confidence for large-scale trajectory climatology studies. The Wall analysis tool in trajectory climatology studies has been used to statistically derive meridional and zonal flow of air over the subcontinent (Tyson *et al.*, 1996). Transport from Kitwe has been examined between the low and mid-troposphere. Average transport pathways to the subcontinent from Kitwe have been determined for February (summer), April (autumn), July (winter) and October (spring) between the 850 and 700hPa. Trajectories for these geopotential heights have been calculated kinematically. A five-year trajectory climatology has been calculated from Kitwe. The transport levels chosen for 1990-1994 aimed to capture transport below the absolutely stable layers in the low-to-mid troposphere during rain and non-rain days. The absolutely stable layers observed over southern Africa play a large part in trapping aerosols below their bases and promoting horizontal transport at those levels.

The study of transport pathways from the Zambian Copperbelt has been supplemented by trajectory climatologies that have been calculated for the southern African region. Studies on air pollution transportation are mainly carried out based on trajectory analyses of air parcel movement from or towards identified source regions. This study has utilised these trajectories to give an indication of the three dimensional atmospheric transport of aerosols from the Zambian Copperbelt. Forward trajectories provide insight into the transport of aerosol-laden air over and out of the southern African subregion, and more importantly, on the impacts of this transport on neighbouring countries and remote regions. This helps determine the extent to which transportation from the Copperbelt supplements that from the industrialized Highveld in South Africa, itself the major industrial aerosol generator in the region.

Trajectory modeling

A five-year trajectory climatology for 1990-1994 was calculated for the Zambian Copperbelt, centered on Kitwe (12.9º S, 28.2º E, 1262m amsl). Investigations of air parcels were carried out for air at different starting levels in the atmosphere, since average transports vary with altitude (Garstang *et al.*, 1996). This study utilized a trajectory array that is representative of the whole of the Zambian Copperbelt. Forward trajectories, using the D'Abreton Langrangian model, were calculated for the area, and then classified according to major transport pathways, both annually and seasonally. Percentages were then calculated for each transport category and level.

Trajectories were calculated using an estimate of the centerline of an advected air parcel with regards to its vertical and horizontal displacement. Trajectories correspond to individual transport events thus providing an approximate indication of the mean motion of an advected air parcel (D'Abreton, 1996).

Air parcels are advected using

$$x(t+dt) = x(t)+V[x(t)]dt \qquad \text{(Equation 1)}$$

where x(t+dt) is the new three-dimensional air parcel position; V(t) is the air parcel velocity vector, and dt is the time step (D'Abreton, 1996).

The actual advection patterns were calculated using a kinematic frame, which utilizes the three dimensional wind data (point of origin, vertical and horizontal displacement or *u, v w*). Once the 3-dimensional wind values of *u, v, w* were obtained, the parcel was advected for 15 minutes then a new position set, until all the trajectories were advected for the required number of days in the atmosphere (D'Abreton, 1996). The procedure was repeated forward in time for differing pressure levels. The model caters for an advection of up to 10 days forward and backwards from a point of origin. Multiple trajectories may be run from an initial location for numerous levels and for multiple days. For purposes of this study, a five-point cluster was used. Five points were used in order to validate the results of the trajectories. The construction of kinematic trajectories has been found to be acceptable, especially in representing large-scale motion (Pickering *et al*, 1993).

A total of 12 000 trajectories were run for the months of February, April, July and October to represent the summer, autumn, winter and spring seasons respectively. Trajectories beginning at different geopotential heights representative of the lower troposphere (~850-800hPa) and the mid-troposphere (~750-700hPa) were calculated kinematically between 1990 and 1994. Total transportation from Kitwe was classified according to direction and travel distance. Analysis and classification of the transport was based on seasonality and tropospheric level transport.

The D'Abreton kinematic trajectory model

The D'Abreton model is run on input data already set and also caters for parameter input by the user. Input parameters needed to run the trajectory model include:

(i) setting pressure levels (between 10hPa and 1000hPa, in this case, forward trajectories were calculated for the 850, 800, 750 and 700 hPa levels),

(ii) setting year start and year end (a maximum of one year of data is permitted),

(iii) start and end month for which trajectories are to be run (the programme caters for leap years for the month of February),

(iv) longitudinal limits of data domain (-60 to -120) and latitudinal limits of data domain (-60 to -30).

Files (*.dat*) were created for each month for which trajectories were run. Input months overlap one another to cater for back trajectories for the subsequent month, and forward trajectories into which the trajectories will be flowing. For example, October 1990 data was obtained from the octnov90.dat data file. A gridded data set was used to run trajectories from a cluster. In this case a five-point cluster was used to determine trajectory starting point, thus:

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to represent the starting point of each trajectory. A 2.5º resolution was used, such that the staring point for each trajectory was:

1. -12.9º 28.2º

2. -10.4º 28.2º

3. -12.9º 25.7º

4. -12.9º 30.7º

5. -15.4º 28.2º

where latitude south is negative. Trajectories were then stored in *g.meta* output files.

Owing to variations in relief and large-scale disturbances over the region, the trajectory model utilized a terrain following routine. Assumptions that the effects of wind shear and vorticity are negligible were made when using this model. Furthermore, it was assumed that no vertical mixing occurred. The vertical velocities were determined from adiabatic non-linear normal mode initialization which permits the diabatic as well as adiabatic processes, influencing vertical motion (D'Abreton, 1996).

A topographic data file (*601206030topo.dat*) using the same spatial resolution as atmospheric data was used as a correction factor for irregularities in topography. Atmospheric input data for the *u* (point of origin), vertical (*v*) and horizontal displacement (*w*) was used. Trajectory calculations were terminated when the parcel reached the boundary of the data set (as set by the monthly limit, zonal (north-south) and meridional (east-west) direction).

Trajectories were run for all the days for the months of February, April, July and October starting at 12.00 UTC, and a time step of fifteen minutes (after every 15 minutes the position of the trajectory would be indicated as a point *x*10hPa) (Figure 2.1) The average number of days a trajectory at each pressure level would take to complete the grid would then be calculated, together with the standard deviation of time taken.

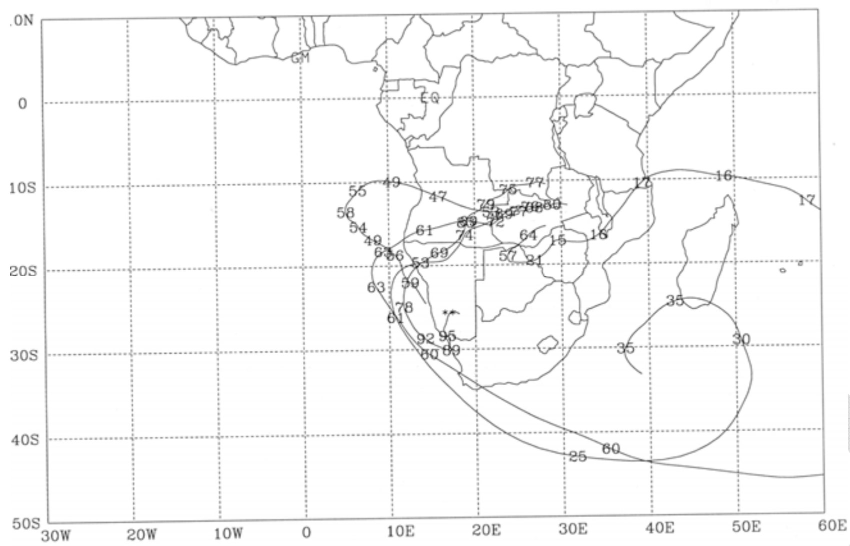

Figure 2.1 Five point trajectories from Kitwe indicating trajectory time steps for every fifteen minutes.

Existing files could then be edited to run trajectories for a specific month (within the data set provided by the ECMWF), and an executable file (*.gmeta*) created in order to view the trajectories thus created.

Trajectory modeling, however, only provides an *estimate* of the transport pathway of an advected infinitesimally small parcel of air, and not a positive long term trend of the pathways and destinations of pollutants.

Statistical Analysis of Trajectory Data using the Wall method.

The Wall programme uses output data from the D'Abtreton trajectory model as its input data. The output data for the wall programme is forward circulation statistics, since forward trajectories were run. Composite zonal and meridional transport fields were derived for the subcontinent to estimate the extent to which recirculation of air and aerosols may take between the surface and the 700hPa layer (Fig. 2.2).

Total and seasonal frequencies of trajectories originating over Kitwe and crossing international boundaries were calculated to determine the transboundary transport of pollutants. Meridional and zonal planes were selected at 2° intervals extending from 10°E to 40°E and 10°S to 40°S respectively (Fig. 2.2). Walls were constructed for westerly, easterly, southerly and northerly transport for each of the interval levels below the 700hPa level. Trajectories at 850hPa, 800hPa, 750hPa and 700 hPa levels, from Kitwe passing through each grid cell of the meridional planes were then computed, as were the total number of trajectory hits in each cell. The example below (Fig. 2.2) illustrates a single trajectory moving from Kitwe in a westerly direction. The plume rises and by the time it reaches meridional grid wall 20°E, it has risen to 850hPa. The trajectory exits the continent at 750hPa only to recirculate and re-enter the continent at around 25S. It hits the 30° S zonal wall at 750hPa and eventually exits the continent at 30°S at the 800hPa level (Fig. 2.2). Similar trajectories were constructed at 2 interval for southern Africa between 10 and 40° S and and 10 and 40° E. The grid of trajectory hits from Kitwe on each meridional and zonal grid plane is interpolated, and converted to percentages. The trajectory frequencies were then used to draw the transport plume extending westwards and eastward (meridional), and southward and northward (zonal) from the point of origin for the site.

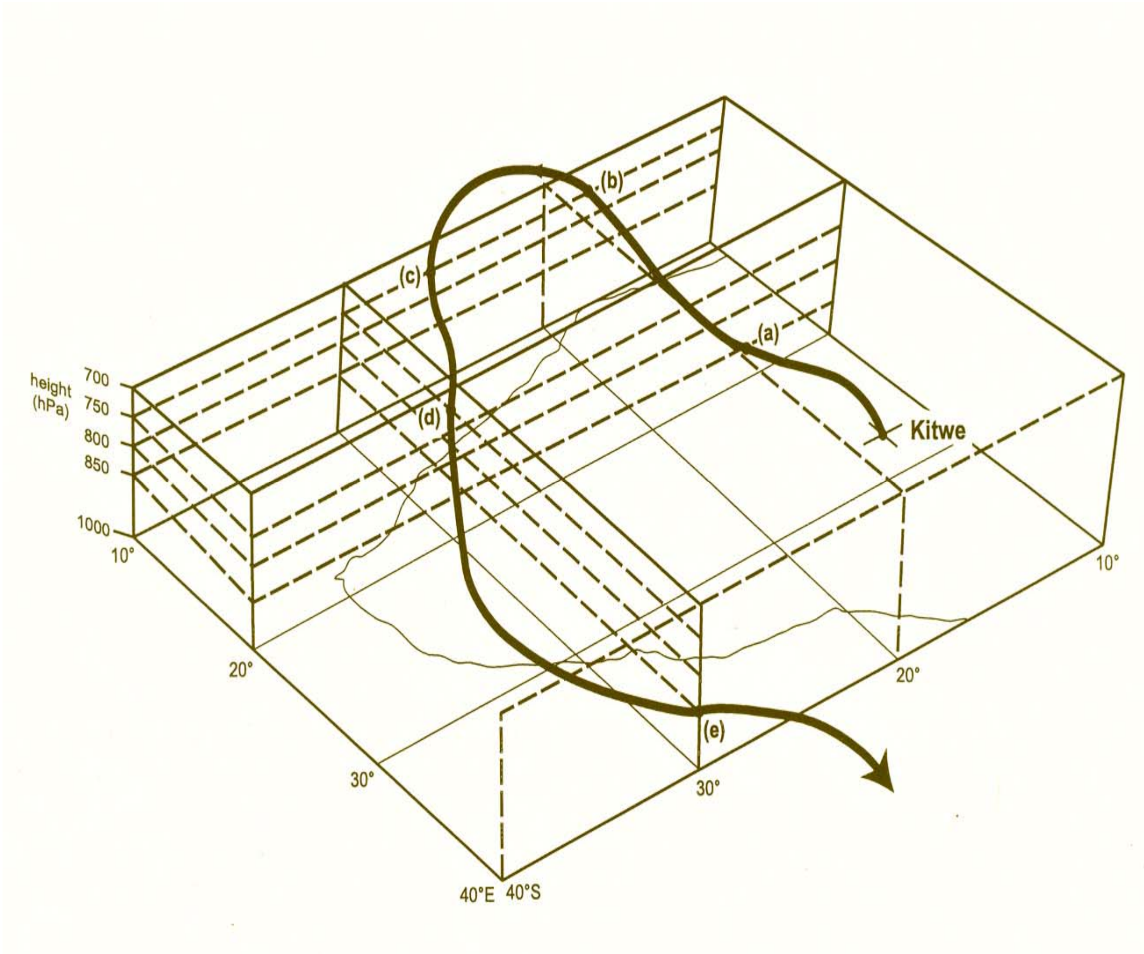

Figure 2.2 Meridional (10°E-40°E) and zonal (10°S-40°S) walls constructed for Southern Africa, between approximately 1000hPa to 750hPa.

Output data from the wall programme was then used to plot contours that give the intensity and direction of transport from the starting point. Transport direction from contour plots only indicates initial starting direction from a point of origin. The contours, however, give a clear visual effect of transport behaviour for the study area.

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A seasonal air transport climatology was calculated using ECMWF input data for 1990-1994. Forward trajectories were run for summer, autumn, winter and spring for the five-year period. Output data from this modeling was used to construct walls at 2º interval zonally from 10º to 40ºS, and meridionally from 10º to 40ºE. These walls were used to plot contour transport direction and frequency from the starting point. The results from these calculations and their significance are discussed in the next Chapter.