CHAPTER SIX : SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 SUMMARY

Measurements of the vertical distribution of ozone, aerosol number density and size distribution have been made over the sites Thumba and Hyderabad. The measured values are used to calculate the attenuation coefficients at different altitudes for different wavelengths and their relative importances in the radiative transfer problems are discussed. This section summarises the work done and the important results.

**OZONE**

Rocket-borne ozone measurements have been carried out from equatorial rocket launching station situated at
Thumba (8.5°N). The technique involves the measurement of the attenuation of the incoming solar radiation using UV photometers operating in the wavelength region of 240-320 nm. The laboratory measured ozone absorption cross section values are converted into effective cross section values as a function of altitude, taking the spectral response of the photometer into consideration. After applying correction for Rayleigh scattering and using the effective absorption cross section values, ozone number densities are calculated from the obtained attenuation profiles.

The photometers are calibrated for their spectral and angular response and used on M 100 and Centaure rockets and ozone concentrations have been measured from an altitude of about 16 km to a maximum altitude of about 70 km. For night time ozone measurement lunar UV photometers are designed and developed. These photometers are more sensitive (about 10^5 times) than the photometers used for day time measurements. Night time ozone measurements have been made using these photometers during or near full moon days.

There have been a total of seven day time and two night time measurements carried out since 1980 from which reliable ozone profiles have been retrieved. Also an Indo-USSR ozonesonde intercomparison programme was held during March 1983 at Thumba. The experiment involved near simultaneous measurement of vertical distribution of ozone concentration using different techniques like rocket-borne UV
photometry, chemiluminescent sonde, balloon-borne chemical sonde and ground based Umkehr observation. The results are compared for their accuracy and instrumental bias.

The results of the ozone measurements carried out over Thumba (a total of 19 profiles) are compiled and a mean ozone profile for the equatorial region is constructed. This mean profile is compared with the available satellite measurements for the equatorial region and with the US standard ozone profile for the mid-latitude region. The results of the Intercomparison programme and the comparison of the mean profile with other results are summarised below.

1. Near simultaneous measurements with Soviet and PRL optical ozonesondes show that the results agree within $\pm 20\%$, the maximum random errors of measurement in the altitude region of 25 to 50 km.

2. Ozone concentration values measured below 25 km differ from sensor to sensor. These differences are beyond the stated random errors in the measurements. Whether this observed differences are genuine representing short term fluctuations in ozone concentration at these levels or are due to instrumental behaviour needs further study.

3. Comparison of the rocket data with ballon data shows that the balloon ozonesonde overestimates the ozone concentration if the balloon burst level is below the ozone peak.
4. The night time ozone concentrations measured both using lunar UV photometers and chemiluminescent ozonesonde show a definite increase over the day time values above 50 km. This is qualitatively in agreement with the photochemical model predictions. However the night time measurements made by the Soviet chemiluminescent sonde during the March 1983 experiment show higher values at all altitudes above 26 km. It is difficult to understand the increase in the ozone values at stratospheric levels using photochemical models. Further it has not been possible to rule out an instrument bias. This needs further study. The observed percentage increase in the night time ozone concentration values are compared with other published results. While the results agree qualitatively, the percentage increases are found different at different altitudes. Since water vapour plays an important role in the mesospheric ozone concentration, the observed differences between the individual measurements could only be explained with the simultaneous measurement of water vapour concentration and other relevant parameters like temperature and vertical eddy diffusion coefficient at mesospheric level.

5. The mean ozone profile is compared with the other published satellite data viz. NIMBUS 7, Solar Maximum Mission and Atmospheric Explorer-E satellite for the equatorial
region. In general the present mean value compares well with the satellite data in the altitude region of 20 to 50 km. Below 20 km the satellite values (SBUV) are found to be lower. While balloon-borne ozonesonde can overestimate the ozone, satellite data may also give incorrect values at low altitude levels. This is because the larger wavelength used in the back scattering technique for low altitude ozone measurement requires prior knowledge of climatological conditions. Marked differences are found between different results at altitudes above 50 km. It should be noted that each individual result is a mean of a number of measurements and hence not biased to any particular season. It is known that at mesospheric altitudes ozone chemistry is strongly influenced by solar activity and by other minor constituents like HO\textsubscript{X} radicals. However measurements of the HO\textsubscript{X} concentration at these altitude levels are sparse. The cause for the observed differences could partly be due to variations in some of these parameters. Simultaneous measurements of absolute solar flux, water vapour concentration and mesospheric temperature along with ozone measurements will help in explaining the observed differences.

6. Comparison of the mean equatorial ozone profile with the mid-latitude model shows the latitudinal variation in the vertical ozone concentration. It is well known that the
total ozone content over equator is less than that over higher latitudes. This difference is mainly due to the ozone concentrations at altitudes below 30 km. The present model equatorial ozone profile exhibits ozone peak at a higher altitude, 27 km compared to mid-latitude model which shows the peak at 22 km. The peak ozone concentration of the equatorial model is also lower corresponding to $3.45 \times 10^{12}$ molecules/cc compared to $4.86 \times 10^{12}$ molecules/cc over the mid-latitude regions. These latitudinal differences are explained mainly in terms of transport found at tropospheric and stratospheric levels. However the in situ production of ozone at tropospheric levels over mid-latitudes cannot be neglected.

**AEROSOL**

A new approach has been used to obtain aerosol number density and size distribution. The technique involves the measurement of direct solar radiation and the angular distribution of the scattered radiation intensity. Scattering functions are determined at various altitude levels for different scattering angles. The angular variation of the obtained aerosol scattering function is compared with the theoretically computed values and slope of the power law size distribution curve is estimated. From the ratio of the aerosol scattering function to Rayleigh scattering function the number density of particles is obtained.
This method has been used to analyse the data from three rocket measurements of direct and scattered radiation over Thumba during February 1980. Aerosol number density and size distribution function could be obtained from 5-22 km. Success of this technique promoted the design and development of a new sun-tracking photometer system. The field of view of the photometers is reduced using baffles and logarithmic amplifiers are used for higher dynamic range so as to extend the measurements to higher altitudes. This sun-tracking photometer was flown twice from Hyderabad. After the failure of the first balloon launch the second launch in April 1984 yielded reliable data. Aerosol number density and size distribution function could be obtained up to the balloon ceiling altitude. The results of the rocket and balloon measurements are summarised below.

1. Aerosol measurements made over Thumba during February 1980 show layered structures at low altitudes in all the three cases. The density is found to be few hundred particles per cubic centimetre below 10 km and few tens/cc in the 10-15 km range. There is a deep minimum in the aerosol concentration profile near the tropopause. Above this minimum, in the lower stratosphere, aerosol number densities are found to be few particles/cc.

2. The slope of the power law size distribution curve is found to decrease with increasing altitudes. This shows
the predominance of large particles over small particles at higher altitudes. Matching the experimentally observed scattering functions with theoretically calculated values shows that a unique slope cannot describe the size distribution of particles of radii from $0.04 \mu m$ to $10 \mu m$. An uncertainty of $\pm 0.2$ is found in the determined $\beta$ values.

3. Aerosol measurements during 1984 over Hyderabad show no pronounced layer unlike over Thumba at low altitudes. Satellite measurements have shown that at tropospheric levels condensation nuclei concentration is more over equatorial region than over mid-latitudes. However measurements of the aerosol extinction coefficient for $1 \mu m$ by satellite at stratospheric levels always show a higher optical depth at mid-latitudes than over equator. Extinction coefficients calculated from the Thumba and the Hyderabad measurements give larger values over Thumba than over Hyderabad. This increase especially at the stratospheric level is suspected to be due to the near equatorial eruption of Sierra Negra volcano three months prior to the measurements over Thumba.

4. Measurements of the size distribution function over Hyderabad show a constant value of $\beta = 3$ in the altitude region of 10 to 15 km. Data obtained above 21 km show a lower value of 2.7 at 21 km, which increases with increasing altitude. The height distribution of $\beta$ show a layer in
the 21-25 km characterised by larger number of bigger particles which can be associated with the stratospheric aerosol layer. The height distribution of $\gamma$ over Thumba shows the lowest $\gamma$ value at 22 km. Since there is no measurement above this level it is not clear whether the minimum value is reached or not. It can only be concluded that the peak of the layer is at or above 22 km. If the difference (1 km or more) in the level of lowest $\gamma$, corresponding to larger size particles is real it could represent a latitudinal effect.

**RADIATION STUDIES**

Using Mie scattering theory the aerosol scattering coefficients are computed for different wavelengths for the measured aerosol concentrations and size distribution functions over Thumba and Hyderabad. This computation is necessary because most of the satellite-borne aerosol experiments measure the optical depth of the aerosol. So for comparison the aerosol concentration values have to be converted to scattering coefficients/optical depths. Moreover for atmospheric energetics studies the height distribution of the aerosol scattering coefficients is necessary.

Absorption coefficient due to ozone and Rayleigh scattering coefficients are calculated for the equatorial region and are compared with aerosol scattering coefficients
at three typical wavelengths 300, 450 and 600 nm. The results are summarised below.

1. The altitude profiles of the attenuation coefficients show that the ozone absorption is important in attenuating the solar radiation above 16 km for \( \lambda = 300 \) nm and above 20 km for \( \lambda = 600 \) nm. At lower altitudes scattering processes are important.

2. For a typical wavelength region where ozone absorption is not important (\( \lambda = 450 \) nm) both aerosol and Rayleigh scattering are equally important in attenuating solar radiation. At altitudes below about 12 km aerosol scattering is found to be more than Rayleigh scattering over Thumba. However over Hyderabad the aerosol scattering is less than Rayleigh scattering at all altitudes.

3. At 600 nm the aerosol scattering is more than Rayleigh scattering at all altitudes over Thumba while over Hyderabad aerosol scattering is found to be less than Rayleigh scattering at all altitudes. This could be due to the low aerosol number densities and the high \( \sqrt{ } \) values observed over Hyderabad during 1984 giving rise to low scattering coefficients. The result obtained over Hyderabad correspond to a volcanically quiet period.

4. Comparison of the spectral variation of Rayleigh scattering and aerosol scattering shows that the importance of aerosol
scattering increases with increasing wavelength. However, it also depends upon the aerosol number density and size distribution. It is found that the aerosol scattering is more than Rayleigh scattering below 20 km for wavelengths greater than 500 nm over Thumba and for the aerosol distribution obtained over Hyderabad aerosol scattering is higher than Rayleigh scattering for wavelengths greater than 900 nm at altitudes below 20 km.

6.2 SUGGESTIONS FOR FUTURE RESEARCH

The major latitudinal variations in ozone concentrations are found from ground level to about 30 km and temporal variations are at mesospheric levels, above 50 km. While rockets and satellites are best suited for mesospheric ozone studies, at lower altitudes, especially below 20 km, our major knowledge regarding ozone distribution is derived from balloon measurements and Umkehr observations. Umkehr observations have limitations and at lower levels the errors are high due to scattering problems. Balloon-borne chemical sonde requires the knowledge of total ozone content for their calibration and for obtaining the vertical structure of ozone distribution. Also, it can give erroneous results if the balloon does not cross the ozone peak level which is relatively high (at 27 km) over the equatorial region.
Ozone measurement by differential absorption technique using space-borne photometers does not require any absolute calibration and is relatively less biased to the initial guess. Rocket-borne photometers are used to obtain the ozone concentration above 16 km, but below this altitude both Rayleigh and aerosol scatterings play dominant roles in attenuating the radiation. While Rayleigh scattering component can be calculated with sufficient accuracy, knowledge regarding the vertical profile of aerosol scattering is very limited. Also they have high temporal and spatial variations. Using the relatively simple method described in this thesis aerosol concentration and size distribution can be obtained at lower altitudes and the scattering coefficients can be calculated for any wavelength of interest.

Therefore it is suggested that simultaneous measurement of the vertical distribution of ozone and aerosol using optical techniques should be carried out. Photometers operating at few selected wavelengths can be used on balloons for these measurements. For the estimation of ozone concentration altitude variation of solar radiation intensity around 300 nm is to be monitored. For aerosol measurements, direct and scattered radiation of wavelength in the visible and near infrared region but not affected by water vapour absorption is to be monitored. The advantage of this simultaneous measurements is the derived aerosol characteristics can be used to calculate the scattering coefficient for the UV wavelengths used in the
ozone measurement, and hence a more accurate estimation of ozone concentration can be obtained at lower altitudes. It should be noted that unlike in chemical sonde, the balloon burst level does not affect the accuracy and reliability of the obtained data.

Secondly, measurements of the vertical distribution of water vapour and other minor constituents like oxides of nitrogen and chlorine are very limited over the equatorial region. Simultaneous measurements of these minor constituents along with temperature and eddy diffusion coefficients (both vertical and horizontal) are of great use not only to explain the observed variations in the ozone concentration but also to understand the formation and transport of the background aerosol particles.

To explain the observed differences between the ozone concentration values at mesospheric levels and also the day-night variation of ozone, knowledge of solar UV flux values, concentrations of minor constituents like HO\textsubscript{x} radicals are important. These are sparse. Therefore simultaneous measurement of absolute solar UV flux, water vapour concentration and mesospheric temperature along with ozone measurements will help in explaining the observed differences.

Also optical properties of aerosol are important in understanding the short-time-scale climatic fluctuations
and to estimate the role of the aerosols in the atmospheric radiation budget. Owing to the high temporal and spatial variations of aerosols, continuous monitoring of aerosol becomes a necessity. While LiDARs can be used for continuous monitoring of aerosol, ground based sun photometers are relatively cheap and simple to operate. By making measurements of direct solar radiation at few selected wavelengths as a function of solar zenith angle, aerosol optical depths can be obtained (using Langley plots). From the spectral variation of the optical depth, the size distribution function can be inferred. Continuous measurement of this type will help to understand the relative variation of the total particle content and their size distribution. Using Sun tracking mechanism and automatic data recording this technique can be made more versatile. Such measurements at different locations will help to understand the spatial distribution pattern to study the relative drift of the particles. This measurement technique is more suited for the Indian subcontinent where indigenous satellite measurements are yet to be made.