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LIDAR OBSERVATIONS OF THE BOUNDARY LAYER USING AN AEROSOL AND OZONE PROFILER

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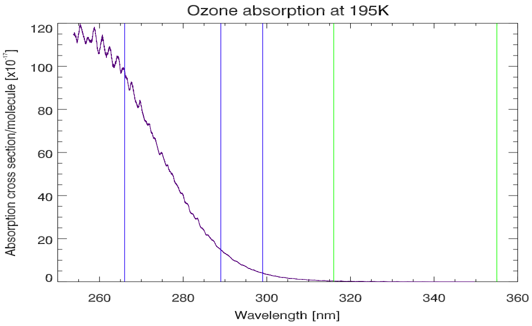

FIG. 1: Ozone absorption cross section for the near ultraviolet showing the wavelengths used by the lidar [courtesy of NASA]

1. INTRODUCTION

The boundary layer is in direct contact with the biosphere, and hence concentrations of aerosol and gas within this layer are of importance to its inhabitants. Through mixing with the free atmospheric layer above, these constituents can be transported to other locations where they can mix back into the boundary layer. This mixing is important, as ozone transported from the boundary layer to the free troposphere can be transported globally and affect the oxidation state of the troposphere as well as influence the radiation balance.

During the summer of 2005 the Convective Storm Initiation Project (CSIP) was carried out in Southern England. Measurements were made directly using aircraft and radiosondes and indirectly using remote sensing instruments such as radar and lidar. The aim of the project was to improve the understanding of convective initiation in the maritime climate of the UK. One of the instruments used was an ozone and aerosol lidar based at Chilbolton in Hampshire, UK. Algorithms were written to retrieve both aerosol and ozone data from the lidar and some preliminary results are presented here.

Fluxes for ozone into the boundary layer over savanna were calculated by Cros et al. (2000). It is hoped that similar fluxes can be derived from the lidar data shown here, as this instrument has the ability to obtain reliable ozone measurements in the boundary layer.

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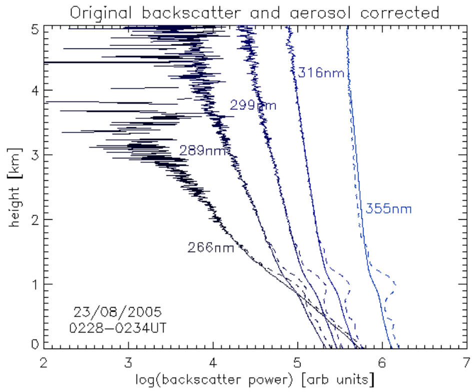

FIG. 2: Backscatter power for the 266nm, 289nm, 299nm, 316nm and 355nm beams for 0228UT-0234UT on 23/08/2005. The measured backscatter (dashed) and the backscatter corrected for aerosol absorption (solid).

2. THEORY

Aerosol measurements can be used to observe the vertical structure of features in the boundary layer. As the convective boundary layer grows, moisture is transported vertically until it meets an inversion and has insufficient energy to penetrate higher. This leads to a temporary boundary between the clean, dry free-tropospheric air and the moisture and aerosol laden boundary layer beneath. This boundary is used in the aerosol lidar data to calculate the boundary layer height. This transition is not a distinct step but a transition zone termed the 'entrainment zone' (EZ). It can vary in thickness depending on the strength of the inversion and the vertical speed of the thermals. When the thermals (or plumes) overshoot the inversion due to inertia, free-tropospheric air becomes entrained into the boundary layer at the edges of these thermals (Deardorff et al., 1980; Sullivan et al., 1998). If the inversion is not strong enough to stop these thermals, they can then rise to the next inversion. If this is the tropopause, then convective storms can form.

The retrieval algorithm for ozone concentrations relies on ozone being the primary absorber of ultraviolet radiation in the region of the Hartley band (200-300nm). To obtain ozone values using the DIAL method it is necessary to compare two wavelengths, utilising the fact that ozone absorbtion changes according to wavelength (see figure 1). Aerosol concentration is derived from wavelengths free of ozone absorption.

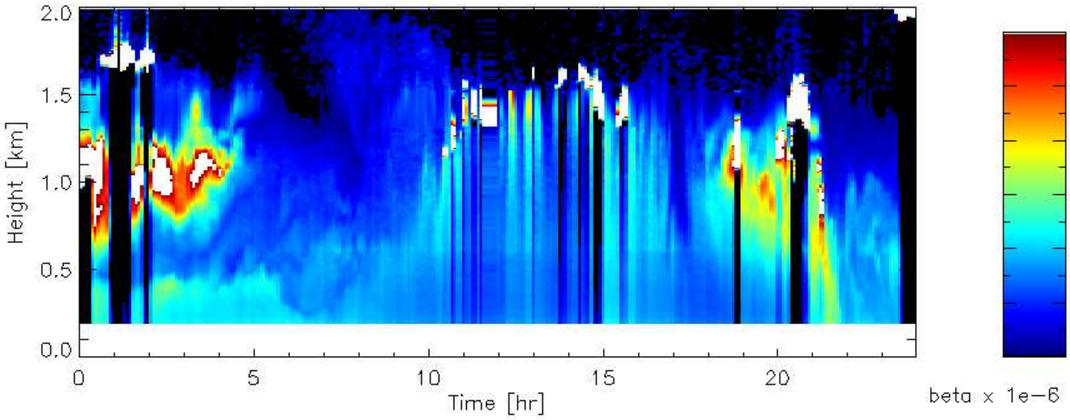

FIG. 3: Plot of aerosol backscatter coefficient on 23rd August 2005 at 316nm using data from the Elight lidar

This aerosol absorption is then removed from the remaining wavelengths and ozone absorption is calculated from the difference in the signal backscatter.

3. INSTRUMENTATION

The mobile aerosol and ozone profiler used is a compact DIfferential Absorption Lidar (DIAL) system manufactured by Elight Laser Systems and operated by the Universities' Facility for Atmospheric Measurement (UFAM) in the UK.

The profiler uses five wavelengths in the ultraviolet ranging from 266nm to 355nm. These wavelengths are chosen to allow simultaneous aerosol and ozone retrieval in the atmospheric boundary layer.

To produce these wavelengths a powerful Continuum PL8020 Nd:YAG laser is used. It produces an infrared beam at 1064nm, which is then tripled and quadrupled to 355nm and 266nm, respectively. The remaining three wavelengths are created by sending the 266nm beam through separate Raman-shifting cells filled with Hydrogen and Deuterium at different pressures. The gas in these cells causes inelastic scattering of the 266nm beam to create three wavelengths of 289nm, 299nm and 316nm.

Backscatter profiles at all five wavelengths were recorded to computer in both the near and far fields, providing a range from 100m to 5km, depending on meteorological conditions. The altitude resolution is 7.5m and the time resolution is variable but normally set to 3 minutes to minimize dataset sizes.

4. RESULTS

Figure 1 shows the absorption cross-section for ozone. At 266nm, 289nm and 299nm the beam experiences increased absorption by ozone, whereas 316nm and 355nm show little to no significant ozone absorption. When the derived aerosol backscatter is subtracted from the 266nm, 289nm and 299nm signals, ozone concentrations can be calculated using the differential absorption technique. Figure 2 shows a backscatter profile for 23rd August 2005 showing the measured profiles and the backscatter power adjusted for aerosol absorption. Aerosol absorption is calculated by detecting and defining a layer of zero aerosol in the 316nm and 355nm beams and using this as a reference to determine the change in absorption caused by aerosol. The gradient of the slope indicates the absorption by ozone, most noticeably in the 266nm beam.

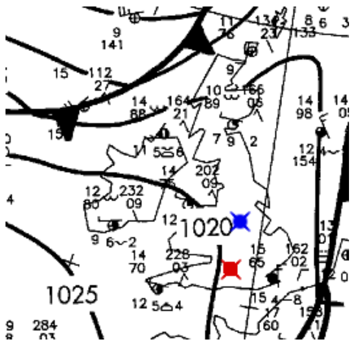

FIG. 4: Surface pressure chart for 23/08/2005 at 00UT showing a ridge of high pressure over the UK. The lidar was based at Chilbolton (red cross) and the radiosonde ascent is from Nottingham (blue cross) to the North [courtesy of Deutscher Wetterdienst].

4.1 *Aerosol Retrieval*

An aerosol backscatter plot for 23rd August 2005 is presented in figure 3. The time resolution is 5 minutes and the vertical resolution is 7.5 metres. During the night, two layers dominate the profile. Up until 04UT a layer at about 1km shows a significant increase in aerosol

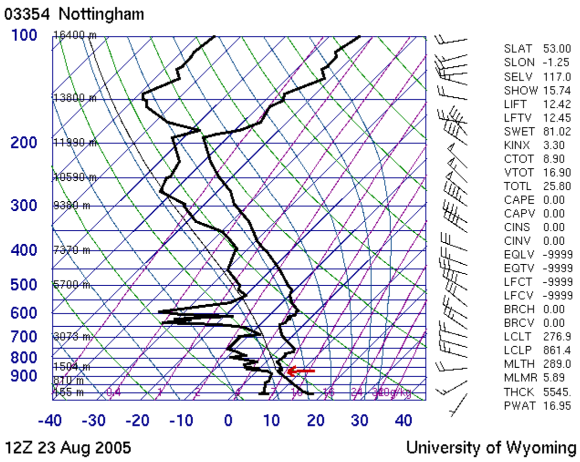

FIG. 5: Radiosonde ascent for Nottingham in central England on 23/08/2005 at 12UT. The arrow shows the inversion. [courtesy of University of Wyoming]

(up to 3 times the surrounding air). This is believed to either be a polluted layer or a residual layer from the previous day. A trajectory analysis and observations from the previous day will show the origins of this air parcel.

The second layering of interest is the lowest 500m. This is believed to be the stable nocturnal layer. About an hour after sunrise (0505UT) this layer is soon perturbed and the growth of the boundary layer can be observed reaching between 1.3km and 1.5km from 11UT onwards. The aerosol backscatter coefficient in the boundary layer is around 2x10^{-6} and less than 1x10^{-6} in the free troposphere. Figure 4 is a surface pressure chart for 00UT on 23rd August 2005, showing a ridge of high pressure over the UK. The ridge led to an inversion (see figure 5), capping the boundary layer at about 1.5km. Cumulus clouds formed throughout the day and created problems with the aerosol retrieval algorithm. Figure 2 also shows discrepancies caused by high aerosol backscatter at 1km and an alignment problem causing increasing 355nm after the aerosol signal has been removed.

4.2 *Ozone Retrieval*

Using wavelength pairs of aerosol corrected signals allows the calculation of ozone profiles. The wavelength pairs used are 266nm/289nm, 266nm/299nm and 289nm/299nm. Currently the ozone retrieval is only reliable between 0.7km and 1.1km. This is due to a discrepancy in the splicing of near and far field data around 0.6km and some ringing in the lidar system at about 1.3km. Figure 6 shows ozone concentrations averaged over heights 0.7km to 1.1km for 23/08/2005. All three signals show an increase in ozone concentrations as the boundary layer grows through this layer. Again cumulus cloud causes anomalies in the ozone data. The 266nm/289nm and 266nm/299nm ozone values correlate closely and the same trend is observed in all three datasets. The 289nm/299nm values, however, are slightly above the other two. Looking at the ozone absorption in figure 1 reveals that the difference between 289nm and 299nm is smaller, making the ozone retrieval more sensitive to errors.

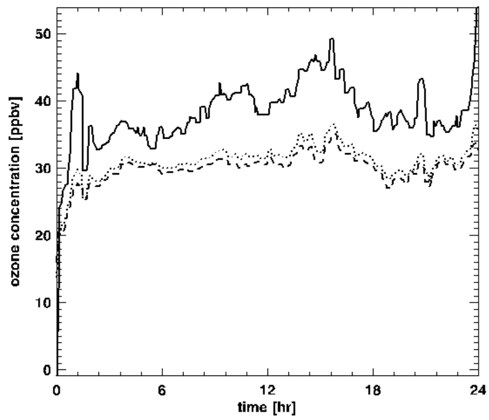

FIG. 6: Ozone concentrations averaged between 0.7km and 1.1km for 23/08/2005 using differential absorption with wavelength pairs 266nm/289nm (dashed), 266nm/299nm (dotted) and 289nm/299nm (solid line).

5. CONCLUSIONS

Aerosol and ozone retrieval algorithms have been successfully applied to obtain measurements of boundary layer growth and the ozone concentrations within it. Nocturnal and residual layers were also detected. These preliminary results can be improved upon by adjusting the algorithms to cope with low-level cloud. This will allow the more complete retrieval of aerosol and ozone profiles of the lower troposphere and detailed analysis of boundary layer structure.

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