P2.10 AN ANALYSIS OF METEOROLOGICAL FACTORS THAT INFLUENCE BOUNDARY LAYER OZONE CONCENTRATIONS USING OZONESONDE DATA FROM VALPARAISO, INDIANA, PELLSTON, MICHIGAN, AND HOUSTON, TEXAS

Ashley D. Mefferd[1], Gary Morris[2], Craig Clark[1], Bryan Johnson[3]

[1]Department of Geography and Meteorology, Valparaiso University, Valparaiso, Indiana
[2]Department of Physics and Astronomy, Valparaiso University, Valparaiso, Indiana
[3]NOAA Earth System Research Laboratory, Boulder, CO

1. INTRODUCTION

This study presents ozonesonde data from three sites: Valparaiso, IN, Pellston, MI, and Houston, TX. Sixteen launches occurred from the campus of Valparaiso University during the one-month period from 19 April through 16 May 2006. Thirty-six launches occurred from Pellston during the time period 1 July through 8 August 2004. These two data sets will comprise most of the analysis presented here. Data from Houston is used to compare ozone conditions in the boundary layer.

Each flight consists of data with approximately one second resolution, ascent rates around 5 m/s, maximum altitudes between 20 and 30 km, and total flight times of about 2 hours. Only the lowest 3 km of the atmosphere were investigated in this study in order to concentrate on boundary layer conditions. The cut-off of 3 km was chosen since most boundary layer structure above normal vegetation in the mid-latitudes is below this level.

2. BOUNDARY LAYER CHARACTERISTICS

The software environment R was utilized for visualization and analysis. We first grouped the ozone data into three different categories: high, mid and low ozone days. The categorization criteria examined the 0.25 km ozone concentration. All days for which the 0.25 km ozone concentration is more than one standard deviation above the mean are classified as high ozone days. It is important to note that none of these days actually exceeded EPA air quality standards for ozone. The highest 0.25 km ozone level in our study was 66 ppb on 21 July 2004.

All days for which the 0.25-km ozone concentration is more than one standard deviation below the mean are classified as low ozone days. The remaining days are classified as mid ozone days.

Within each category, we examined the meteorological variables. Table 1 shows the average 0.5 km potential temperature (theta) value and the average 0.25 km ozone concentration for the designated categories. The average potential temperature of low ozone days appears to run about 10 K lower than the average potential temperature of high ozone days. This behavior is expected since warmer temperatures are synonymous with higher ozone concentrations.

	0.5 km Mean Theta Value	0.25 km Mean Ozone Concentration
Low Ozone Days	288.8 K	0.01625 ppmv
Mid Ozone Days	294.5 K	0.03763 ppmv
High Ozone Days	298.5 K	0.05689 ppmv

Table 1. Average theta and ozone values for each of the three calculated ozone categories from all Valparaiso and Pellston data.

3. AVERAGE MIXED LAYER HEIGHTS

Using the same categories, we calculated the average mixed layer height. Our original hypothesis suggested that higher surface ozone concentrations would be associated with shallow mixed layer heights due to the reduced volume in which ozone could be mixed. This hypothesis was proven false by the average mixed layer height calculations.

The high ozone category days had the highest average mixed layer height at 1.73 +/- 0.56 km. Expectedly, the mid ozone days had an average mixed layer height at 1.51 +/- 0.53 km. Finally, the low ozone days had an average mixed layer height of 1.02 +/- 0.41 km. An interpretation of our data suggests that higher mixed layers allow more interaction with the lower free atmosphere, where higher values of ozone are typically found at these two sites. The days that had lower mixed layer heights were unable to utilize the higher ozone concentrations above the boundary layer.

Sample profiles were taken from each category to plot theta and ozone concentration with height. Figure 1 shows profiles from Pellston on 5 July 2004, a low ozone day. The top of the mixed layer was detected around 0.85 km by the inversion in theta and large increase in ozone. Ozone concentrations near the surface are approximately 20 ppb while the lowest theta reading was 292 K.

* Corresponding author address: Ashley D. Mefferd, Dept. of Geography and Meteorology, Valparaiso University, 1809 Chapel Dr., Kallay-Christopher Hall, Valparaiso, IN 46383; e-mail: Ashley.Mefferd@valpo.edu

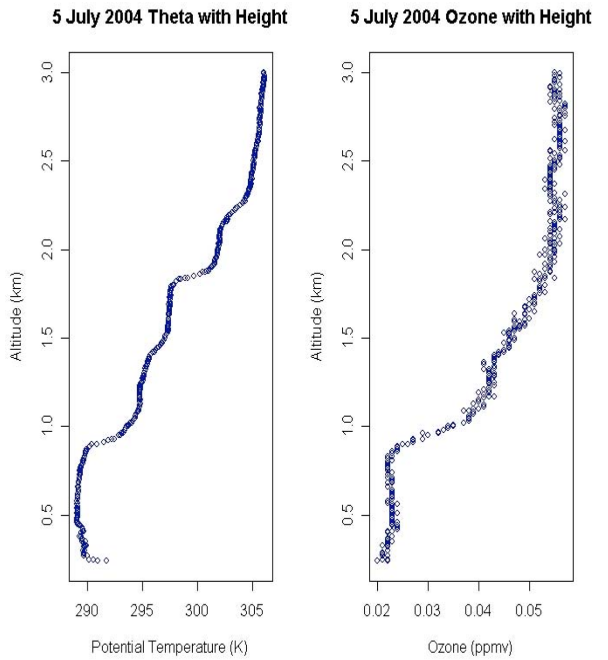

Figure 1. Potential temperature and ozone profiles from Pellston, MI on a low ozone day. Steep increases in both variables indicate a shallow mixed layer. Low values of each variable are also evident.

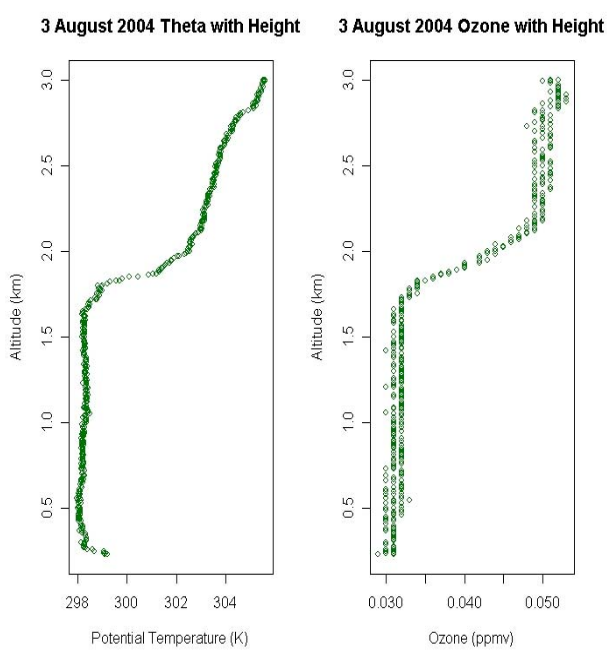

Figure 2. Potential temperature and ozone profiles from Pellston, MI on a mid ozone day. Steep increases in both variables indicate a mixed layer height of approximately 1.75 km.

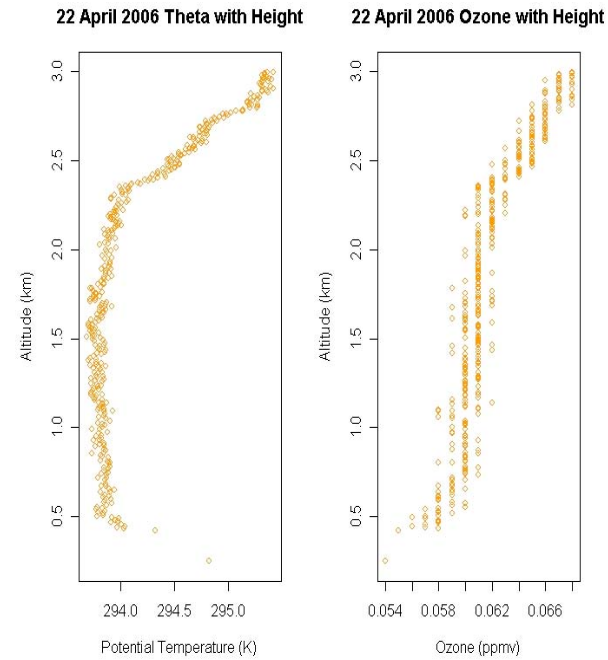

Figure 3. Potential temperature and ozone profiles from Valparaiso, IN on a high ozone day. Steep increases in both variables indicate a deep mixed layer. High values of each variable are also evident.

Figure 2 shows profiles from 3 August 2004, a mid ozone day with a mixed layer height of approximately 1.75 km. Ozone concentrations near the surface on this day were about 30 ppb while the theta value was 299 K.

Figure 3 shows profiles from 22 April 2006, a high ozone day, from Valparaiso. The top of the mixed layer appears at 2.4 km with a surface ozone concentration of 54 ppb. Even though the average theta value for high ozone days is higher than mid ozone days, 22 April 2006 shows a theta value of approximately 295 K. The lower potential temperature as compared to the other two examples is due to the seasonal temperature difference, this being an April reading as opposed to a July or August readings. Higher ozone amounts can occur under cooler conditions.

Although higher mixed layer heights are associated with higher ozone concentrations in Valparaiso, Indiana and Pellston, Michigan, the result is site dependent. Neither of these sites have major ozone precursor sources. In these regions, higher ozone concentrations are located above the boundary layer in the free atmosphere, most likely from upwind sources such as Gary, Indiana or Chicago, Illinois.

Unlike Valparaiso and Pellston, the Houston area contains abundant sources of ozone precursors. In Houston, ground level ozone can reach extremely high levels under favorable meteorological conditions. A shallower mixed layer height will trap the ozone close to the surface, increasing surface concentrations. Mixed layer height cannot be used alone as an explicit predictor for ozone concentration.

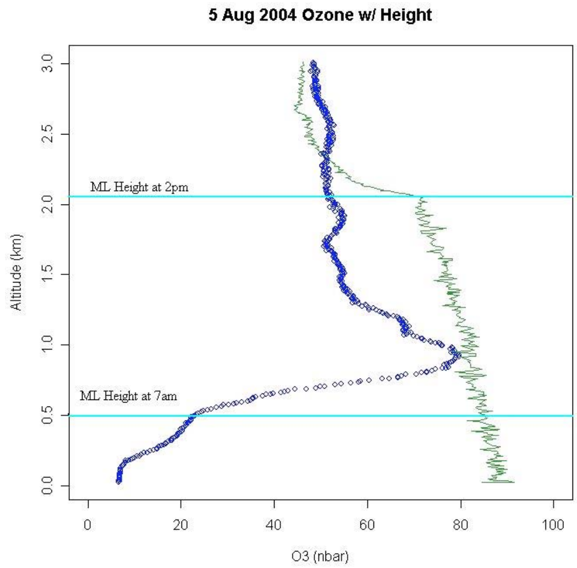

Figure 4. Ozone profiles from two separate launches on the same day from Houston. The blue profile represents the 1200 Z launch while the green profile indicates the 1900 Z launch. Mixed layer heights are designated by the cyan line, the lower line from the 1200 Z launch.

3. EVOLUTION OF THE BOUNDARY LAYER

A number of variables affect the ozone concentration throughout the day. For example, the day's meteorological conditions are a major influence on the production, dispersion and elimination of ozone. However, before the day's weather develops, it is also important to know what the ozone conditions were like from the previous day. Entrainment from the previous night's residual layer allows yesterday's ozone to affect today's concentrations. An estimated 50-70% of the day's total ozone concentration comes from ozone that has been blended down through vertical mixing from the residual layer. The rest of the ozone is produced photochemically during the day or advected from another region (Neu et al., 1994).

The evolution of the boundary layer can be examined through data from multiple launches of ozonesondes in Houston on 5 August 2004 shown in Figure 4. The first launch of that day took place at 1200 Z, when the boundary layer was still very shallow before the sun's heating could result in vertical mixing and growth of the mixed layer. A mixed layer height of 0.5 km is observed for this morning profile. The second launch occurred at 1900 Z and reveals a mixed layer height of approximately 2 km. In a seven hour time span, the boundary layer depth increased by ~1.5 km.

As shown in Figure 4, ozone concentrations in the mixed layer increased substantially between the two launches. At 1200 Z, the ozone partial pressure at the surface was below 10 nbar. Much higher concentrations of 80 nbar are found in the residual layer (around 1.0 km). The high concentration in the residual layer resulted from the high levels of ozone found in the previous day's mixed layer (~90 nbar) being trapped as the nocturnal boundary layer set up.

The 1900 Z profile, also seen in Figure 4, reveals a partial pressure of more than 80 nbar at the surface. Between the time of the morning launch and the afternoon launch, ozone photochemical production, increased vertical mixing from heating, and entrainment of ozone from the residual layer resulted in increased mixed layer concentrations. The 1900 Z reading is observed to be even higher than the concentration seen in the residual layer because of additional formation of ozone through photochemical processes. This diurnal cycling of ozone between the residual layer and the mixed layer is one of the many factors that influence the day's ozone concentration.

4. LINEAR REGRESSION

For the Valparaiso and Pellston data, a multi-variable linear regression was used to determine whether the 0.25 km ozone concentration could be predicted from boundary layer temperature and moisture conditions. The following environmental parameters were chosen as the four explanatory variables: 0.5 km relative humidity, 0.5 km potential temperature, 1.0 km potential temperature and 1.5 km potential temperature. Results from the regression model, found in Table 2, indicate the relative significance of the variables and their interaction terms.

Residuals:

Min	1Q	Median	3Q	Max
-0.017688	-0.006341	0.001647	0.006568	0.017057

Coefficients:

	estimate	Std. Error	t value	Pr(>|t|)
Intercept	1.310 e+01	4.719 e+00	2.776	0.00788 **
0.5 km RH	-3.598 e-04	1.213 e-04	-2.965	0.00474 **
0.5 km Theta	-4.585 e-02	1.657 e-02	-2.767	0.00806 **
1.5 km Theta	-4.476 e-02	1.556 e-02	-2.878	0.00601 **
0.5 & 1.5 km Theta	1.573 e-04	5.454 e-05	2.883	0.00592 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.009051 on 47 degrees of freedom
Multiple R-Squared: 0.6112 Adjusted R-squared: 0.5781
F-statistic: 18.47 on 4 and 47 DF, p-value: 3.512e-09

Table 2. A result table from the linear regression model of environmental parameters that affect ozone. The left column includes the four significant variables in the model while the right column indicates their p value.

A model using all four explanatory variables and their interaction terms had no significant terms but a multiple R squared value of 0.7404. The least adequate model contained four significant variables with p-values all under 0.01 and a multiple R squared value of 0.6112. The four significant terms were the 0.5 km relative humidity, 0.5 km potential temperature, 1.5 km potential temperature and the interaction between the 0.5-km potential temperature and the 1.5 km potential temperature. Plots of the regression results (not shown) illustrate a good linear fit between the model predictions and observed ozone.

5. SUMMARY AND CONCLUSION

Ozonesonde data from Valparaiso, Pellston, and Houston were analyzed to understand more clearly the characteristics of an ozone profile in the surface mixed layer. Data were classified by statistically defined ozone categories. Average mixed layer heights were calculated from profiles within each category. At these two sites, both of which are found in areas of lower ozone precursor production, higher ozone levels were associated with a higher mixed layer height. Higher mixed layer heights meant an increased ability to entrain the higher ozone concentrations aloft, likely transported from source regions upwind or downward from the stratosphere.

Investigation of the evolution of mixed layer conditions indicates that much of the day’s ozone comes from the previous day’s ozone that has been entrained from the residual layer.

Significant parameters in the determination of ozone categories were, in order of importance, the 0.5-km relative humidity, the 0.5-km potential temperature, the 1.5 km potential temperature, and the interaction between the 0.5 km potential temperature and the 1.5 km potential temperature.

Acknowledgements. This research was funded by the Indiana Space Grant Consortium and by NASA’s Office of Earth Science.

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