6.10 CHARACTERIZATION OF NOCTURNAL JETS OVER PHILADELPHIA DURING AIR-POLLUTION EPISODES

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1. INTRODUCTION

One of the most significant and interesting processes in the evening boundary layer transition over flat terrain is the development of the Nocturnal Jets or Low Level Jets (LLJ's). Nocturnal Jet flows, from the mid-west regions of the United States, associated with high-pressure circulation, transports continental dry air into the region at a height near 500 m just above the nocturnal inversion, causing a strong characteristic signature in the meteorological conditions. Investigations have shown that there are many possible causes for the LLJ's such as inertial oscillations, mountain and valley winds, land and sea breezes, advective accelerations, synoptic-scale baroclinicity associated with weather patterns, baroclinicity associated with sloping terrain and other processes [Stull, 1998]. As a sub-category of LLJ's, these nocturnal jets can be partly explained by frictional decoupling at night, i.e. the action of cooling at the ground in decoupling the flow just above the temperature inversion from surface friction. This decoupling disrupts the daytime balance of forces in the horizontal and produces an acceleration of the flow above the atmospheric surface layer in a manner described by Blackadar [1957]. A thin stream of fast moving air usually referred to as Low Level Jets is produced as a result of this acceleration. LLJ's attain maximum wind speeds between 10 to 20 m/s and are usually located at 400-800m above the ground. These nocturnal jets generally form during the nighttime over land under clear sky conditions but are destroyed just after sunrise, at which time solar heating and vertical mixing erode the wind field. Figure 1 shows the characteristic nose shape that the jet makes in the wind profile at heights between 400-800 m on 1 July 2002. Investigators have associated these Nocturnal Jets with a number of atmospheric processes [Pitchford, 1962; Seaman, 1998; Reitebuch, 2000; Banta, 2001; Clark, 2001]. The importance of nocturnal jets is that significant quantities of ozone and ozone chemistry precursors can be transported at night from upwind urban plumes. Of course, these jets can also transport ozone generated locally during the previous day into other regions such as rural areas that may not substantially contribute to local production during the daytime. An important finding is the intrusion of drier air, often with elevated ozone concentrations, as the LLJ becomes a westerly conveyor of air from the western boundary region in the early morning hours. This paper presents case studies, which show the strong correlation of nocturnal jets with various air-pollution episodes.

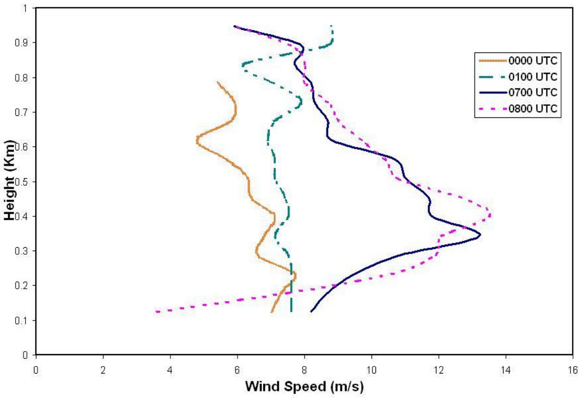

Figure 1. Nocturnal Jet Evolution on 01 July 2002.

2. INSTRUMENTATION AND ANALYSIS TECHNIQUE

A combination of Raman Lidar and wind profiling Radar/RASS systems were used to study the presence of low-level jets over Philadelphia during the NARSTO-NEOPS (North American Research Strategy for Tropospheric Ozone – North East Oxidant and Particle Study) 1999, 2001 and 2002 case studies. During these summers, several LLJ's were observed by the Radar/RASS while simultaneous measurements of water vapor mixing ratio and ozone concentrations were taken using the Raman lidar [Philbrick, 2000].

The PSU Lidar Atmospheric Profile Sensor (LAPS) system uses Raman scattering techniques to measure vertical profiles of aerosol extinction, water vapor, temperature and ozone [Philbrick, 2002]. Water vapor mixing ratio is calculated by taking the ratio of the return

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signal of the 1st Stokes vibrational Raman shifted signal from water vapor divided by that from nitrogen and multiplying by a calibration factor. Ozone measurements are obtained by Differential Absorption Lidar (DIAL) analysis of the Raman signals of N_2 (284 nm) and O_2 (277 nm) which occur on the steep side of the Hartley absorption band of ozone. Vertical profiles of ozone are calculated from the slope of the ratio of Raman-shifted O_2 and N_2 signals.

The wind profiling radar measures the radial Doppler velocity in the North-South and East-West planes, as well as, in the vertical direction in order to compute the wind velocity. The generic name “profiler” comes from the radar’s ability to show data for many heights of the atmosphere at the same time, thus giving a profile of the atmosphere. The wind profiling radar uses refractive irregularities and particulates in the atmosphere as targets. The profiler computes height by using the time interval between transmission of the pulse and reception of the echo. The wind speed and direction are determined by measuring the Doppler shift in the frequency of the return signal. The Radio Acoustic Sounding System (RASS) provides profiles of virtual temperature using vertically directed acoustic waves measured by the radar profiler to determine the speed of sound. The atmospheric temperature is then calculated from virtual temperature using the Raman lidar water vapor profiles.

3. RESULTS FROM NEOPS

Measurements obtained from the NARSTO-NEOPS investigations in Philadelphia during the summers of 1999, 2001 and 2002 have been analyzed and they document the influence that nocturnal jets have on modifying the properties of the residual boundary layer. Several periods show meteorological control and transport of air mass in the signatures of Radar/RASS and Raman Lidar.

During the summer of 1999 the strongest and longest ozone episode was seen during the period 15 - 19 July . Figures 2, 3 and 4 show the wind profiler data along with time sequence plots of ozone and water vapor mixing ratio obtained on 17July 1999. Westerly transport into the region began during the early hours of 17 July 1999. Figure 2 indicates the presence of nocturnal jets in the wind profiler data. Wind speeds from the southwest reach 14 ms^{-1} near local midnight on 17 July 1999. The LLJ is evident at its characteristic height of 400-800 m and is seen to die out near sunrise. The LLJ is found to be partly responsible for the ozone and ozone chemistry precursor transport from the Ohio valley and western mid-Atlantic region.

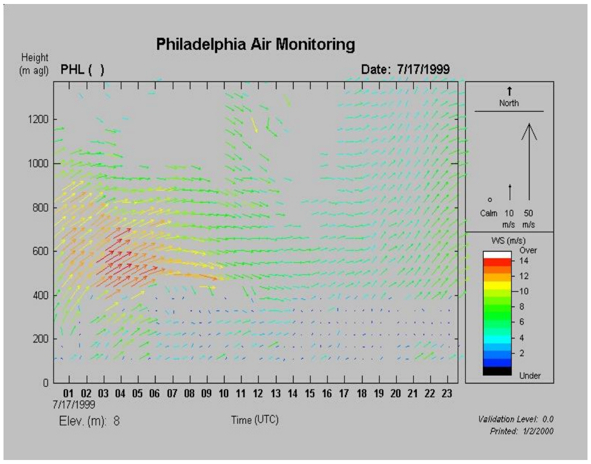

Figure 2. Wind profiler data showing evidence of LLJ’s between 400-600 m AGL on 17July 1999.

The LLJ's were present on several nights between 16-19 July 1999 due to the presence of high pressure circulation in the southeast region of the United States. The data obtained from the profiler clearly indicate the presence of the nocturnal jets from the early hours of 17July 1999. By this time a complex recirculation had occurred with a strong LLJ from the southwest within the nocturnal residual layer. The LLJ was seen to grow in intensity as the episode matured and diminished on 19 July 1999 as the cold front approached. Table 1 provides a brief description of the episodes documented in 1999.

Table 1. 1999 NE-OPS Episodes (Clark, 2001)

Date	Description of Episode
Jul 3-5	Warm Sector, high temps (37.2C), strong low level wind, Code Orange O_3
Jul 8-10	Frontal Passage 7/8, warm sector 7/9 with strong 850 hPa advection. Moderate wind, Code Yellow O_3 with Code Orange west of site.
Jul 15-20	Strongest O_3 episode of season. Ramp-up and recirculation event followed by stagnation. Weak W to SW wind with strong Bermuda High. Many (17) 1-hour exceedances on 7/19. Ramp-up [$PM_{2.5}$]. SW LLJ’s evident during 16-19 July.

Jul 23-24	Recirculation late 7/22 followed by SW 12 ms^{-1} wind and Code Orange O_3. Upper level ridge brings warm 850 hPa temps. TRW's end the episode on 7/24.
Jul28-Aug1	Lower 0_3 levels 7/28-7/30 with W wind followed by lee trough on 7/31, SW wind, spike of 165 ppbv O_3 and passage of sea breeze front. Mobile trough on 8/1 ends the episode. High [$PM_{2.5}$] correlate with low [O_3] .
Aug 4-5	High O_3 levels distributed by frontal passage, NW 12 ms^{-1} winds and low T_d keeps O_3 in Code Orange. Reduced temps.
Aug 11-13	Warm sector, recirculation of high O_3 before passage of bay breeze, strong bay breeze on 8/12 cleanses.
Aug 16-17	Similar meteorology to Aug 11-13 with spike in O_3 on 8/17.

Figure 3 and 4 shows time sequence plots of ozone concentration and water vapor mixing ratio obtained from the LAPS instrument during the early hours of 17July 1999. The figures show the Raman lidar data with a smoothing filter of thirty minutes and displayed with a five-minute step for ozone and five minute smoothing with one minute step for water vapor profiles. Figure 3 indicates the high ozone concentration that developed during the episode due to the westerly transport into the region. Figure 4 shows the characteristic signatures of the nocturnal jets in the water vapor mixing ratio. The dry layer observed near 500 m in the water vapor mixing ratio is due to the transport of drier continental air from the Ohio valley. The co-location of the LLJ with the dry layer is evident in the time sequence from the PSU Raman lidar [Clark, 2001].

Summer 2001 was cool and dry in comparison to the warm and dry summer of 1999, because of the frequent intrusion of continental air in 2001. Episodes in 2001 were fewer in number than those in 1999 but the presence of LLJ's during these periods indicate their relative influence from the combination of both, the local and regional pollution sources. Table 2 gives a brief description of the episodes in 2001.

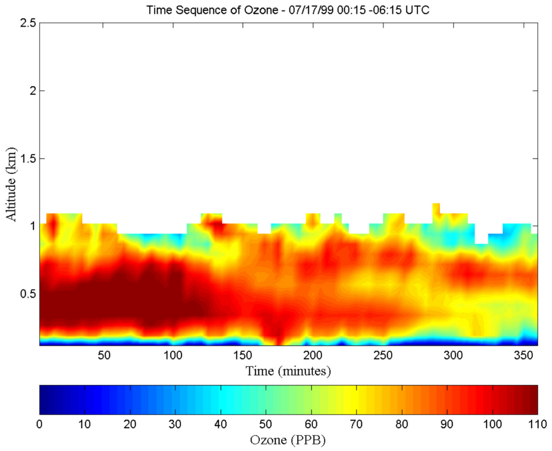

Figure 3. Time sequence of Ozone on 17July 1999 using PSU Raman Lidar.

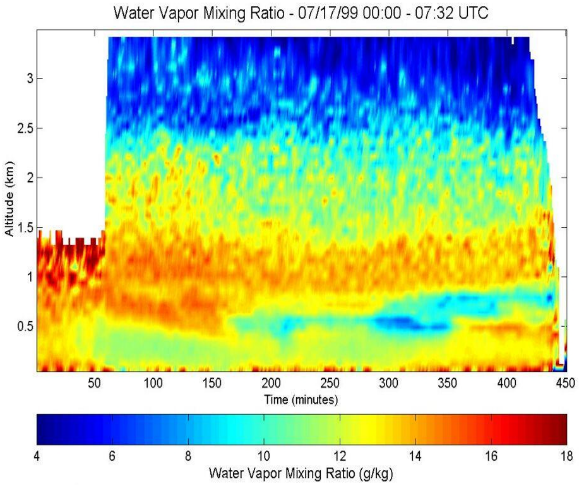

Figure 4. Water vapor mixing ratio from PSU Raman lidar.

Table 2. 2001 NE-OPS Air-Pollution Episodes.

Date	Description of Episode
July 8-10	Recirculation brings WSW winds, temp > 30 C, leading to single day spike in O_3, followed by strong afternoon convection. SW nocturnal jets observed with speeds reaching 14 ms^{-1} during the night of 8 July.

July 17	Highest O_3 (120 ppbv) in July at site, convergence between backdoor front in NY and disturbance in the Midwest.
July 21-25	Sustained high 0_3 associated with northward movement of Bermuda High. LLJ's were observed during the early hours of 24 and 25 July. 100+ ppbv O_3 measured on 25 July.

The NEOPS-DEP 2002 summer campaign also captured a large number of high ozone air pollution episodes over the Philadelphia region.

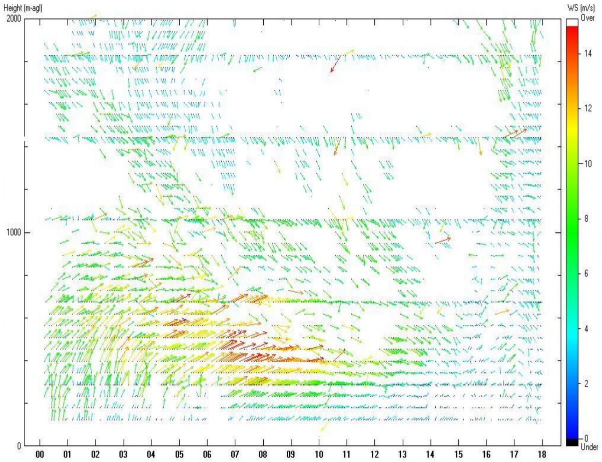

Figure 5. Wind profiler data on 2 July 2002.

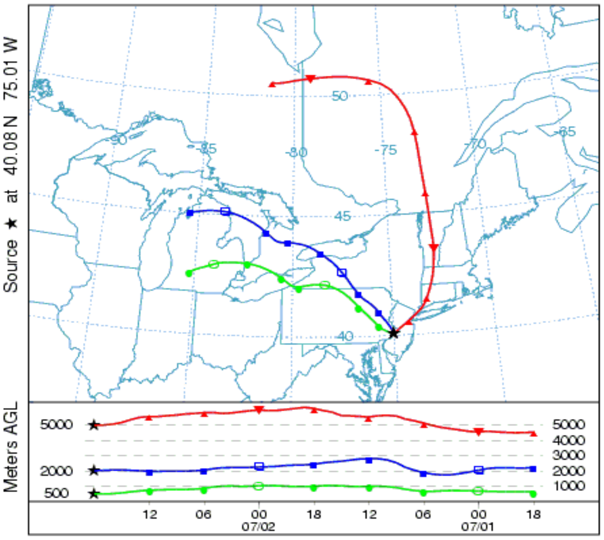

Figure 6. Back trajectories ending at 18 UTC 2 Jul 02 (NOAA - http://www.arl.noaa.gov/ready.html).

The data obtained from the profiler clearly indicate the presence of low-level nocturnal jets during these high ozone periods and corroborates the fact that LLJ's play an active role in the development of major air-pollution episodes. Figure 5 shows the data obtained from the Radar/RASS wind profiler on the 2nd of July, during the 1-4 July episode. The profiler follows the development of the nocturnal jet during each of these nights and it is clear that that the nocturnal jet plays a role in the processes that control the episode. Figure 6 shows the back trajectories obtained from NOAA at Philadelphia on 2 July 2002.

Figure 7 shows another example of LAPS lidar ozone measurement on 2 July 2002. High ozone of 100+ ppbv is seen at a height of about 500 m. The ozone that is aloft is prevented from mixing to the ground as the vertical mixing and wind is decoupled from the surface by the nocturnal inversion. The ozone and its precursors are transported aloft by the nocturnal jets and contribute in addition to the high ozone that develops the next day in the region. Table 3 provides a brief documentation of the presence of LLJ's during the NEOPS-DEP 2002 campaign.

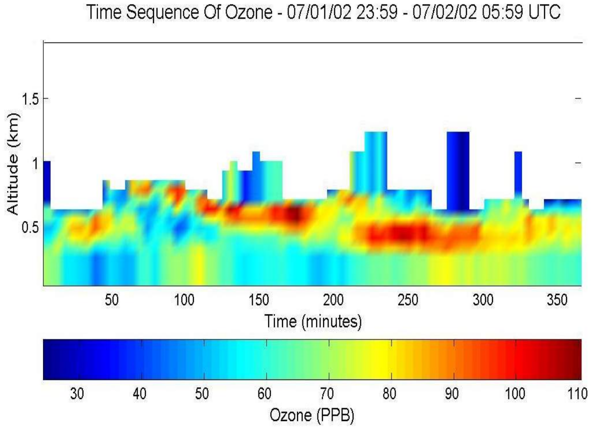

Figure 7. Time sequence of Ozone on 2 July 2002 using PSU Raman Lidar.

Table 3. Nocturnal jets during NEOPS-DEP 2002.

Date	Description of Episode
Jul 1-4	LLJ's were evident with wind speed's reaching 14 ms^{-1} between 400-800m during the early hours of the night in the SW direction. High Ozone episode with O_3> 100 ppbv.

Jul 7-9	Highest ozone period of the campaign with ozone touching 140 ppbv. Strong LLJ's were observed during the nights.
Jul 11-13	Strong Nocturnal jets accompanied with a high ozone (90 ppbv) episode.
Jul 22-24	High ozone with presence of Nocturnal jets.
Aug 8-11	Characteristic nocturnal jets are observed with wind speeds of 15 ms^{-1}

The surface ozone concentration can be seen in Figure 8. The ozone concentration at the surface is seen to touch 120 ppbv during the peak of the episode that lasted from 1-4 July. The surface ozone remains fairly low (20-30 ppbv) till mid-morning. The presence of LLJ's during the nights prior to high ozone days indicates the important role that they play in the processes controlling the high ozone air-pollution episodes that were investigated during these campaigns.

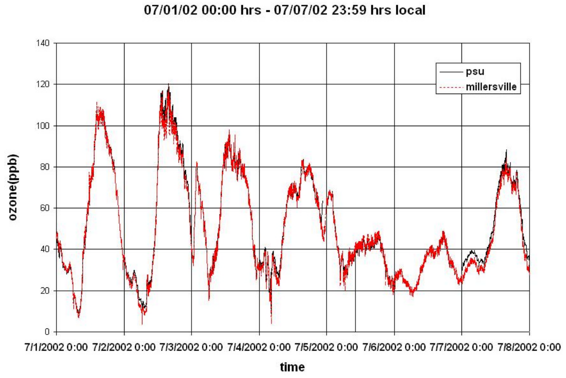

Figure 8. Surface ozone measurements from PSU and Millersville University instruments at the NE-OPS field site.

4. CONCLUSION

Data obtained from the Radar/RASS wind profiler and the PSU Raman lidar during the NEOPS 1999, 2001 and 2002 campaigns have provided an insight into the relationships between the nocturnal jets and high ozone air pollution episodes. These results corroborate the fact that the nocturnal jet plays an important role among the processes that combine to generate air-pollution episodes. It is evident that the nocturnal jets transport significant amount of pollutants from the Ohio valley and mid-Atlantic region into Philadelphia during most of the major episodes. This transport is a factor when high ozone levels are observed at the surface during the day. Future research and analysis will help in characterizing the exact effect nocturnal jets have on the local and regional conditions.

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