3.22 SURFACE PRESSURE MEASUREMENTS AND GRAVITY WAVE MONITORING DURING THE OKLAHOMA CITY JOINT URBAN ATMOSPHERIC DISPERSION STUDY 2003

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1. INTRODUCTION

It is now recognized that gravity waves are an integral part of stable planetary boundary layer (PBL) dynamics. However, the details of the interactions between waves, the mean flow, and turbulence are still under investigation. For example, Finnigan (1999) examined the possibility of scaling wave-turbulence interactions in the stable PBL, and Zilintinkevich (2002) proposed a theoretical model for third-order transport due to internal waves and non-local turbulence in the stable PBL. These types of studies require mean-flow, turbulence, and wave data; however, such data sets are relatively rare. Too often, in field campaigns one of these components is not observed, and most of the time this is the wave component.

A long-term research goal of the Atmospheric Turbulence and Diffusion Division (ATDD) of NOAA's Air Resources Laboratory is the formulation of an operational parameterization of wave-turbulence interactions for use in air quality and climate models. A parameterization of wave stress due to terrain-launched gravity waves has recently been published, *i.e.* Nappo *et al.*(2004).

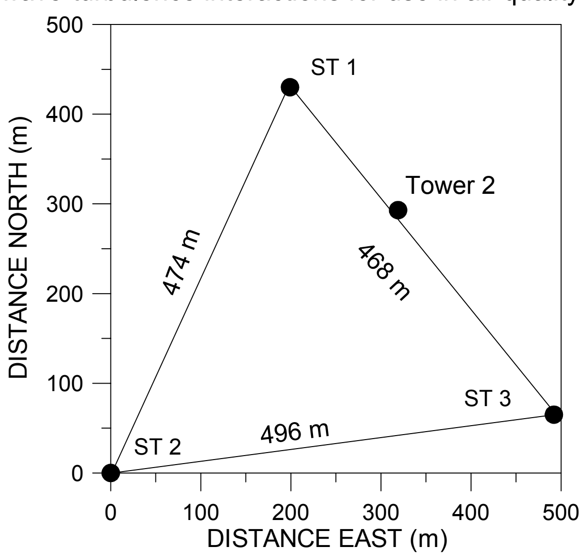

Figure 1 Pressure sampling array.

The more daunting problem is the interactions of turbulence with freely-propagating waves. To facilitate this research, ATDD monitored surface pressure perturbations during the CASES-99 (Poulos, *et al.*, 2001) and VTMX (Doran, *et al.*, 2001) field campaigns. Surface pressure perturbations offer perhaps the simplest and least costly way to detect gravity waves. CASES-99 was conducted in south-central Kansas, a region of flat terrain, and VTMX was conducted in the Great Salt Lake Valley, a region of complex terrain. In both instances, the pressure observations were made over open country. The Oklahoma City Joint Urban 2003 Atmospheric Dispersion Study offered the opportunity to monitor waves in an urban setting with accompanying turbulence, dispersion, and mean-flow observations. In this report, we describe the surface pressure instrumentation and measurements, the sampling array characteristics, and present some initial results.

2. INSTRUMENTATION AND OBSERVATIONS

Atmospheric surface pressure perturbations were measured continuously at three locations on the campus of the Oklahoma School of Science and Mathematics. Figure 1 illustrates the configuration of the pressure sampling array. The array geometry approximates an isosceles triangle with sides of lengths 474, 468, and 496 m. Atmospheric pressure was measured with Setra* model 270 pressure transducers. These instruments have an operating range of from 600 to 1100 mb with an accuracy of ± 0.05 % full scale. The inputs to each barograph were connected to a Väisälä SPH 10 static pressure head in order to measure the static component of pressure. Campbell Scientific 21X data loggers recorded data at each instrument site. Figure 2 shows the instrument setup. The data loggers were programed to calculate 10 second average values from 10 Hz samples. Each 10-second average value was subtracted from the previous 10-second value, and the difference recorded. Thus, the recorded pressure is

$$p(t) = \overline{p}(t) - \overline{p}(t - \Delta t) \qquad \textbf{(1)}$$

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* The naming of a product does not constitute a recommendation by NOAA or the Dept. of Commerce.

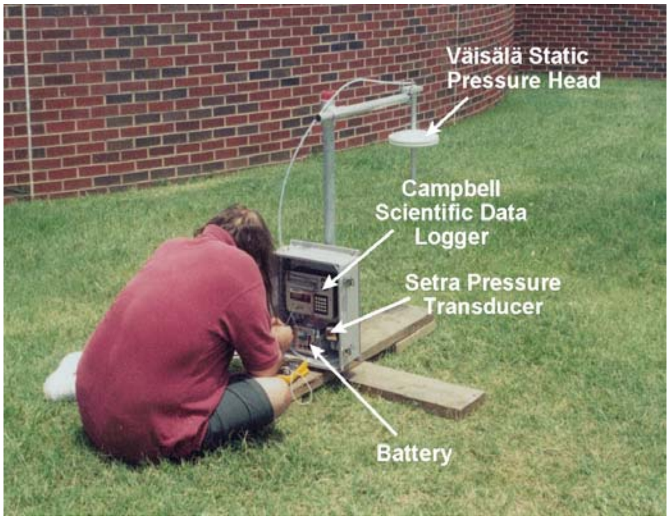

Figure 2 Instrument set-up

where Δt = 10 s, and the over bar indicates a average over 10 s.

3. THE DATA

Observations began on 30 June, 2003, and ended on 1 August, resulting in 29 nights of good data. Of these, about 25 % of the nights showed weak wave activity, about 25 % of the nights showed strong wave activity, and about 50 % of the nights showed

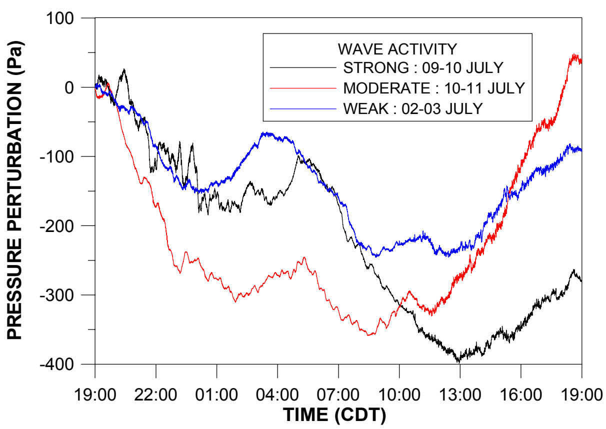

Figure 3 Examples of nights with strong, moderate and week wave activity.

moderate wave activity. These wave activity estimates are relative and based on visual inspection of graphs such as Figure 3 where examples of weak, moderate, and strong wave nights are plotted.

4. ARRAY RESPONSE

The spacings between instruments and the data sampling rate determine the response of the sampling array. The maximum disturbance speed that can be observed with a sampling array is given by (Nappo, 2002)

$$c_{\max} = \frac{D}{2\Delta t} \qquad (2)$$

where D is the average spacing between sensors, which in the present case is about 480 m, and $1/\Delta t$ is the sampling rate. Then c_{max} is about 24 ms^{-1}. Disturbances with speeds greater than c_{max} will be aliased *i.e.*, their energy will appear in frequencies lower than they actually are.

5. SOME EARLY RESULTS

In this section, we present some early results of our analyses to illustrate the utility of these pressure measurements.

5.1 Internal Waves

Figure 4 shows the time series of pressure perturbations observed at the three sampling stations during the night of 5-6 July. From 1900 CDT July 5 (note all times will be Central Daylight Time) to about 2300 July 5, wave activity is weak,

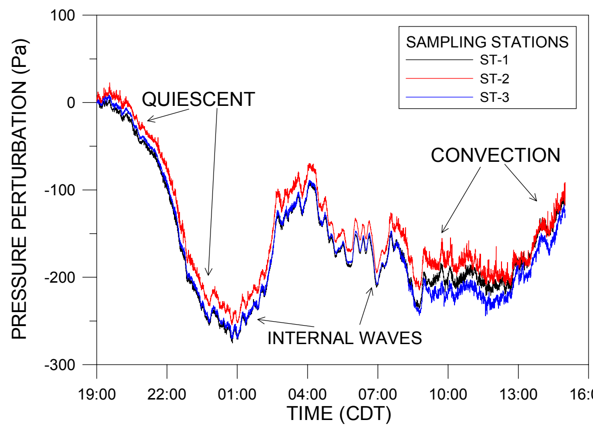

Figure 4 Pressure perturbations observed on 6 July, 2003.

and can be considered quiescent. Waves, which we consider as being internal based on experience, persist from about 2300 July 5 to about 0700 July 6. The amplitudes of these waves appear to increase with time. From about 0900 to 1500, the pressure disturbances reflect convective conditions. Figure 5 shows a wavelet energy diagram (Nappo, 2002) for the period 2300 July 5 to about 0200 July 6. In this analysis, we use the Morlet wavelet which is commonly applied to wave-like disturbances. Although not all disturbances are wave-like, we assume that in the stable PBL they are. From Figure 5, we see that wave-like disturbances with periods between about 15 and 25 minutes persist

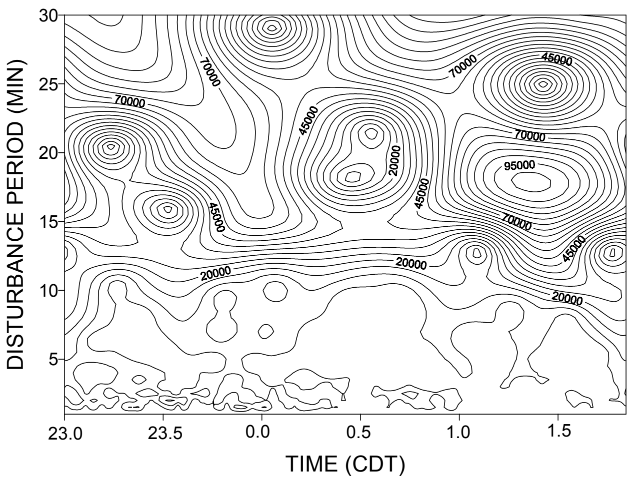

Figure 5 Wavelet energy diagram for Station 1, during the night of 5 - 6 July 2003.

almost continuously throughout the almost two-hour period. We conclude that internal waves with periods between 15 and 25 minutes were present. We next band-passed filtered the pressures at the three sampling stations between these wave periods. Figure 6 plots the time series of pressure perturbations at the three stations. It is clear that the wave amplitude is changing with time and location, which is typical of a wave packet, *i.e.*, a collection of interfering waves. These wave-amplitude modulations may be real, or they may have been introduced by the band-pass filtering.

We leave that 'interesting' discussion for another time. For now we assume they are real. Using lag analysis (Nappo, 2002) and an average wave period of 20 min, we calculate that the wave has a phase speed of 12 ms^{-1}, a wavelength of 14,400 m, and is

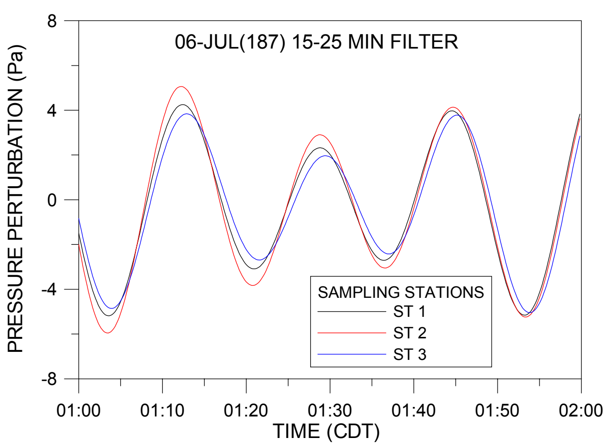

Figure 6 Band-pass filter pressures.

propagating on a bearing of 95E.

5.2 Frontal Passages

Figure 7 shows the time series of pressure perturbation at Station 1 for the night of 29-30 July.

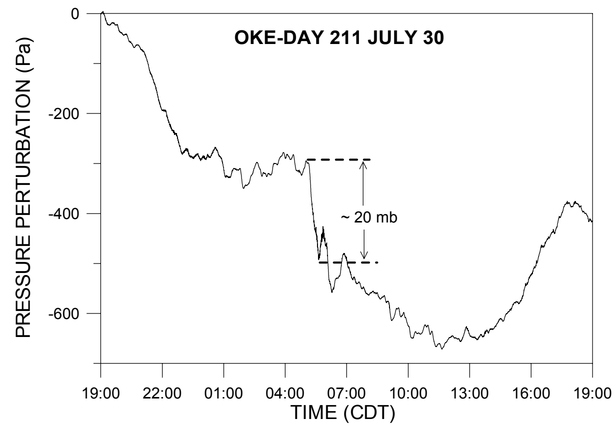

Figure 7 Pressure perturbation at Station 1 for 29-30 July.

Of interest is the almost 20 mb drop in pressure that occurs over a time span of about 37.5 min. Such drops of surface pressure are indicative of frontal passages. Figure 8 shows time series of wind speed and wind direction observed at the National Weather Service office at the Will Rogers World Airport. Between about 0500 and 0600, the wind speed dramatically increases and the wind direction changes by about 90E. Thunderstorms were reported beginning at about 0552 and ending about 0652. Intense thunderstorms were reported at about 0605. A lag analysis showed that the disturbance had a speed of about 6 ms^{-1} and moved

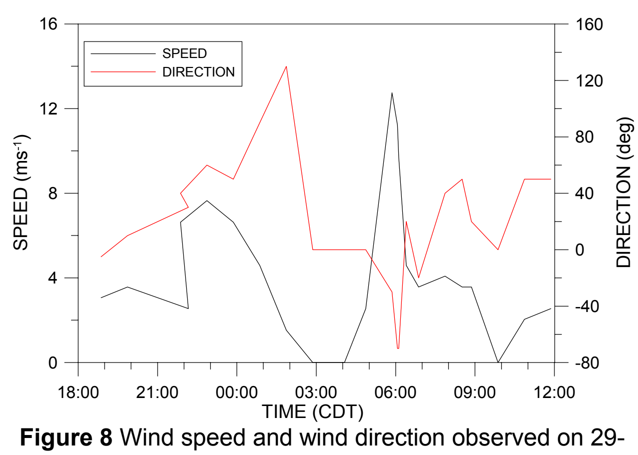

Figure 8 Wind speed and wind direction observed on 29-30 July at the Will Rogers World Airport.

toward the 105E azimuth.

5.3 Waves and Turbulence

As previously mentioned, the interactions of waves and turbulence in the stable PBL is of interest to the ATDD. We have observed that wave-like disturbances appeared on all nights. Figure 9 shows the time series of the unfiltered pressure perturbations observed on 13 July between 0100 and 0300. We see that high and low frequency disturbances occurred on this night. A lag analysis

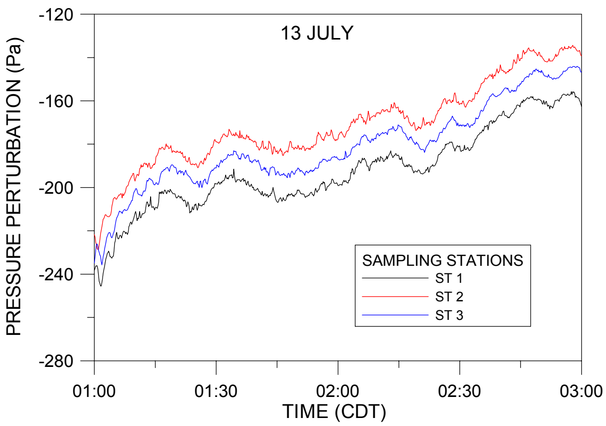

Figure 9 Pressure perturbations observed on 13 July.

for waves with periods between 5 and 25 min gave a phase speed of about 7 ms^{-1} propagating toward about 55E. For an assumed wave period of 15 min, the horizontal wavelength is estimated to be about 6,300 m. Figure 10a shows the time series of turbulence kinetic energy (TKE) calculated as a three-minute running mean, and Figure 10b shows the time series of band-pass filtered (5 to 25 min) pressure perturbations. The TKE was calculated using sonic anemometer data recorded at 7.8 m AGL on the nearby ATDD crank-up tower (Tower 2 in Figure 1). It is clear from Figure 10 that wave-like oscillations exist in both the TKE and the pressure perturbations. However, it is not clear that a correlation exists between the two variables. The running mean calculation eliminates TKE fluctuations on time scales less than three minutes; however fluctuations on time scales greater than three minutes are present.

The analyses of wave-like fluctuations in TKE and their relation with pressure fluctuations is problematical. For example, does one first band-pass filter the velocities before calculating TKE, or does one band-pass filter the TKE after it is calculated? Phase averaging (Nappo, 2002) of the velocities and then calculating TKE is also a possibility. These and other questions will be examined in future research reports.

7. ACKNOWLEDGMENTS

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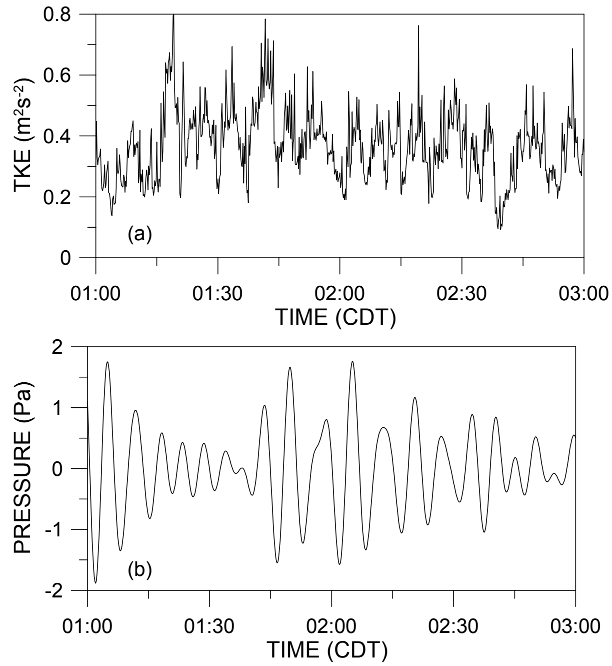

Figure 10 TKE (a) and pressure perturbation (b) for 13 July.

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