Aerosol Transport by Thermally Driven Winds in the Salt Lake Valley

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The analysis of spatial and temporal variations of aerosol concentration in complex-terrain airsheds is key to the prediction of urban air quality. To understand the characteristics, transport and distribution of aerosols in complex terrain air basins, an extensive aerosol ($PM_{10,}$ 0.1-10 μm) sampling campaign was conducted during the Vertical Transport and Mixing (VTMX) experiment over the period October 1-18, 2000. The measurement site was located at a mountain slope in the northeast Salt Lake Valley (Fig. 1). A DustTrak optical aerosol instrument at the height of 2.5 m above the ground was used for surface aerosol measurements. Aerosol concentration was also measured at different heights (up to 500 m) by another DustTrak instrument attached to a tethered balloon, which also carried sondes for the measurements of wind direction, relative humidity, wind speed and air temperature. A 14-m tower instrumented with two sonic anemometers provided further high-resolution flow measurements in support of aerosol transport studies. The aerosol sampling rate for all measurements was 1 min.

The main focus of this communication is to examine the distribution of aerosol concentration during periods with well-developed thermally-driven circulation within the Salt Lake Valley for which the synoptic circulation was largely negligible (the period of October 14-18). Thermally-driven circulation at the Salt Lake Valley with north-south axis orientation (Fig. 1a,b) occurs up-slope during the day (anabatic winds from the west) and down-slope (katabatic winds from the east) during the night [Atkinson, 1981].

Figure 2 shows that for the five-day period of October 14-18 the observed distributions of aerosol concentration, wind direction and heat flux exhibit a clear diurnal cycle. The highest aerosol concentrations are found in the daytime, roughly between the sunrise and the afternoon, and are approximately 2-3 times larger than these found at night. The increased aerosol concentration in the daytime corresponds up-slope westerly winds generated due to surface heating. This flow advects PM_{10} from the nearest source, the downtown of Salt Lake City located about 1.5 km to the west of the test site.

The lowest concentrations of aerosols are found during the period from late afternoon to early morning. During the afternoon and early evening, the wind direction gradually changes from westerly to north-westerly. This change in wind direction can be attributed to the lake breeze, which becomes an important component of the wind field in the afternoon. Thermal contrasts between the land surfaces and the Great Salt Lake generate a system of land/lake breezes which have been detected at various surface meteorological network sites located within the Salt Lake Valley during the VTMX experiment (Doran et al., 2001). A significant decrease of aerosol concentration started roughly 1400 LST (Local Standard Time), which can be attributed to the lake breeze. That is, the air masses containing pollutants are undercut by the lake breeze. The

PM_{10} concentrations stay low until early morning. It is caused by the drainage of cleaner air from the mountain slope after the evening transition when wind shifted from westerly to easterly.

Balloon measurements of the aerosol concentration and wind direction were taken in the nighttime, between the evening and morning transitions. In the late evening, roughly by 2300 LST, and through the night the multi-layer structure was found to form (see Fig. 3a and b). Enhanced PM_{10} concentrations correlate with the southwesterly winds through the city area. Westerly currents at the higher altitudes could appear during the night as a counterpart of easterly down-slope flow (Oke, 1996). The convergence of slope winds at the valley center results in a weak lifting motion followed by divergence of currents moving towards the slopes at higher altitudes. Vertical motions that may arise from the interaction between down-valley and down-slope flows as well as due to the convergence of down-slope winds from the slopes of the opposite mountain ranges have been detected during the VTMX campaign. The observed heat island over the downtown area at night also may contribute to this mean vertical motion. Simulations and field observations showed an approximately 5 cms^{-1} vertical velocity over the center of the basin, which was sufficient to transport an air parcel vertically by 180 m over the course of an hour (Doran et al. 2001). These vertical motions followed by the divergent currents above can provide a mechanism for the pollutant transport from the downtown area towards the mountains.

Shortly after sunrise, the highest PM_{10} values were found near the ground (Fig. 3c). The distribution of PM_{10} concentration measured during the period about 1.5 h starting 10-30 min after sunrise demonstrated a change by a factor of 2 within the layer 100-150 m. This PM_{10} change was detected before the morning transition, which took place roughly in an hour after sunrise. In this period the wind direction is uniformly easterly, from top to 230 m. Based on the temperature profile it should be noted that the multi-layer structure is still prevalent, which influences the vertical distribution of PM_{10} concentration. Thus, enhanced PM_{10} concentrations detected for about an hour after sunrise (though before the morning transition) were provided by easterly drainage flow as well as by elevated winds originating at different slopes (Monti et al., 2001).

In summary, the distribution of PM_{10} concentration appears to be sensitive to the thermal forcing, which exerts the driving influence on thermal circulation within the Salt Lake Valley. For predominantly thermally driven flows at the ground level (i.e. negligible synoptic scale winds), the diurnal variations of PM_{10} concentration are well developed. The daytime flow initially consists of up-slope flows, which advect aerosols from the their source in the city toward the measurement site thus giving high PM_{10} concentrations from mid-morning until early afternoon. In mid-afternoon, PM_{10} concentration decreases significantly owing to the development of northwesterly lake breeze near the ground, which may undercut the up-slope flow carrying pollutants from the downtown area. At night, until early morning low PM_{10} concentrations are a result of drainage of cleaner air from the mountain slopes. Nocturnal vertical distribution of PM_{10} concentration demonstrates that the maximum of aerosol concentration is associated with a westerly return flow aloft while low aerosol concentrations are related to easterly drainage currents.

References

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Monti, P., Fernando, H.J.S., Chan, W.C., Princevac, M., Kowalewski, T.A. and Padyjak E.R., 2001: Observations of flow and turbulence in the nocturnal boundary layer over a slope. (submitted)

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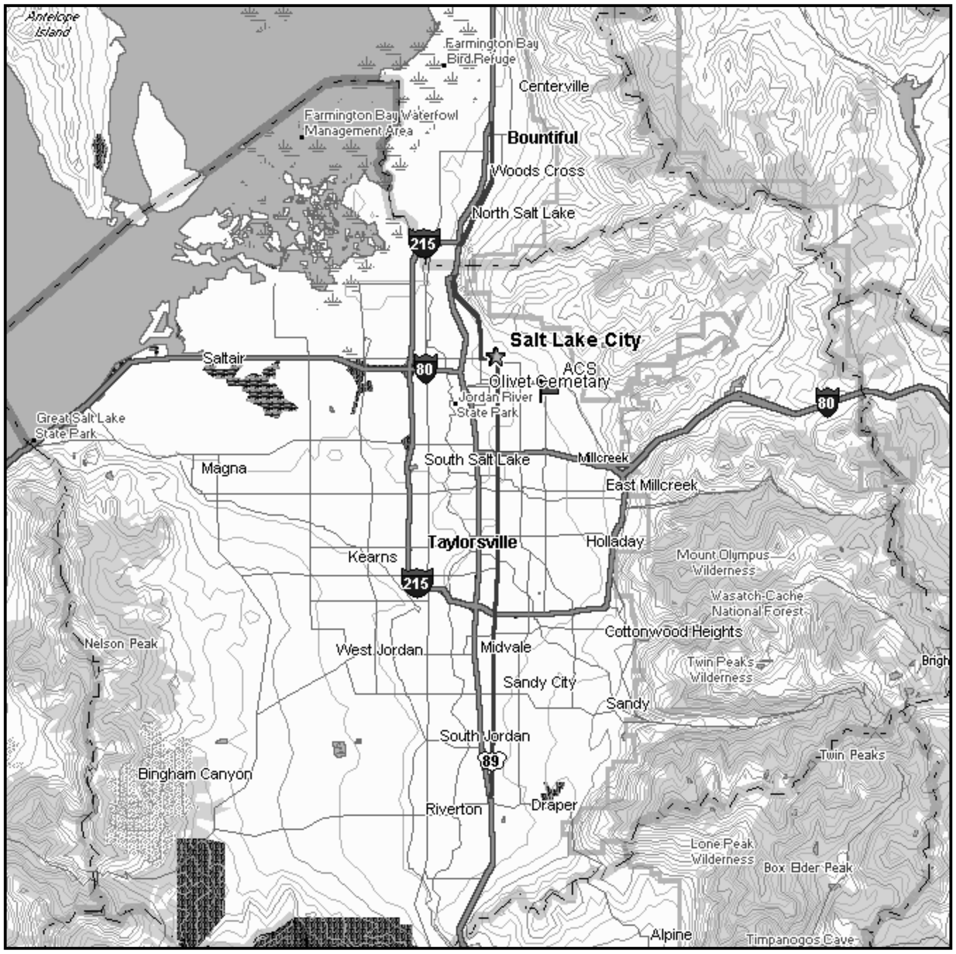
Figures

Figure.1. Topographic contours of the Salt Lake City valley. ACS indicates the site location, N shows the north direction.



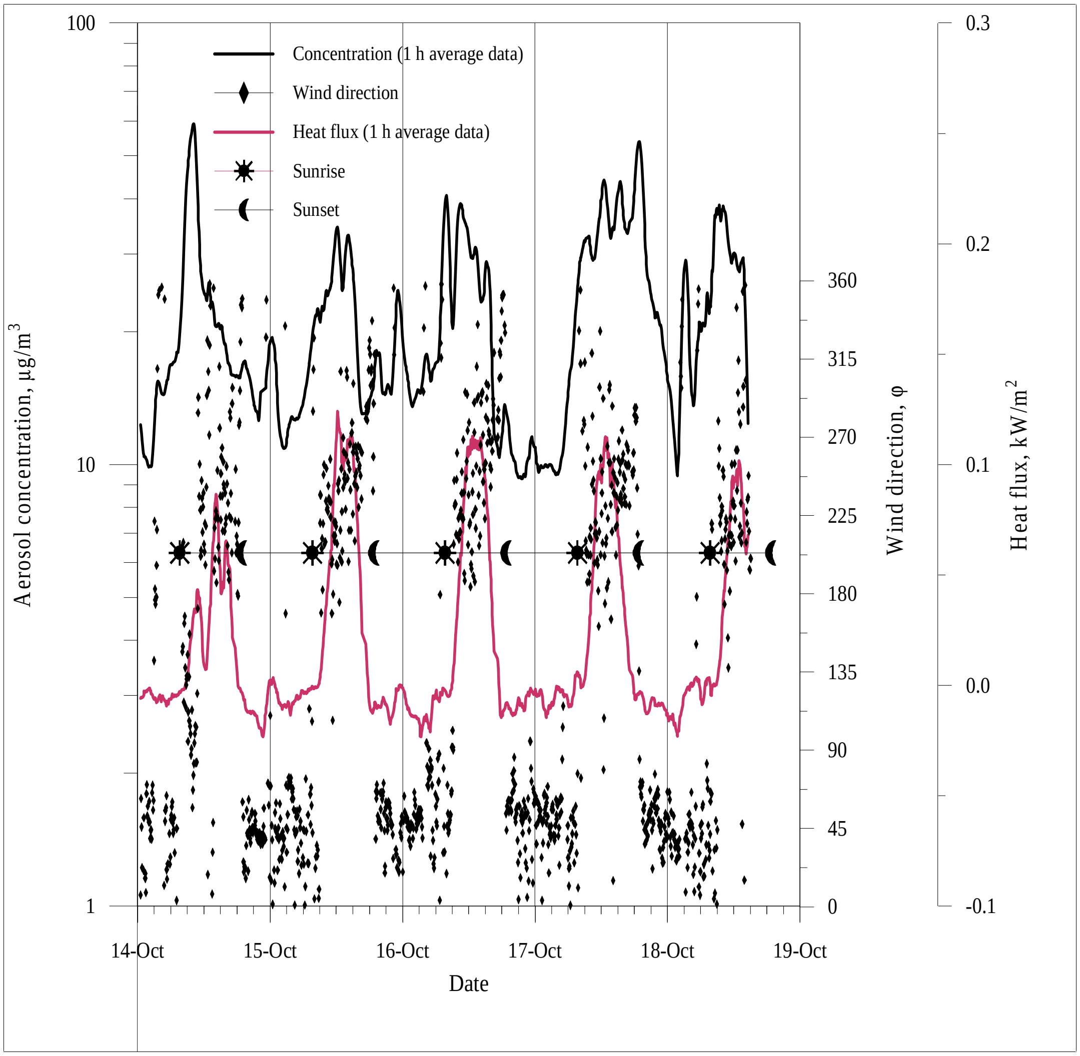


Figure 2. Time series data of aerosol concentration, wind direction and heat flux (Z=2.5 m) for the period October 14-18.

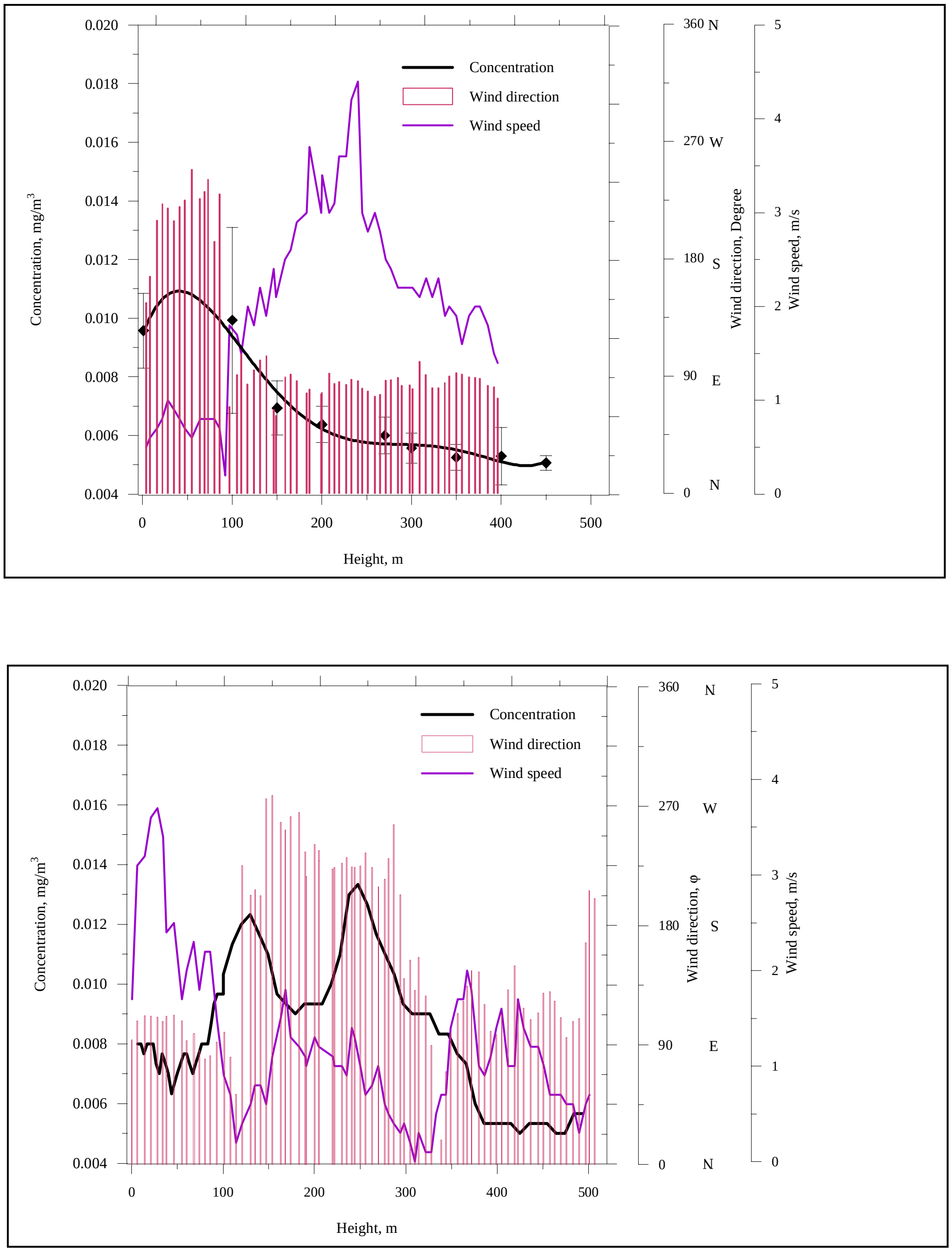


Figure 3. Nocturnal tethered balloon measurements of aerosol concentration, wind speed and wind direction on a) Oct. 16 (2145-0044 LST); b) Oct. 17 (0141-0254 LST);

Figure 3. c) Oct.18 (0801-0930 LST), the morning transition occurred at 0847 LST.