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Relationship between tracer behavior in downtown Salt Lake City and basin-scale wind flow

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1. Introduction

The fate of airborne materials released in an urban area is affected by flows on many scales, including the synoptic-scale background flow and small-scale flows induced by buildings. When the city is located in mountainous or otherwise complex terrain, local-scale topographically generated flows increase the complexity of the transport of the material. In this paper we investigate the behavior of sulfur hexaflouride (SF_6) tracer released in downtown Salt Lake City, Utah, a region where the winds are influenced by several scales of meteorological forcing.

Comparisons of SF_6 tracer dispersion data with Doppler lidar radial wind measurements are presented. Three nights were chosen for investigation because of their differing synoptic-scale meteorological settings. Documenting and understanding the tracer behavior at the building scale is not within the scope of this paper. Rather, here we investigate how mesoscale wind measurements, such as Doppler lidar measurements, may give indications of the characteristics of finer-scale transport in a smaller region. Applications for this type of investigation include air quality (e.g., transport of ozone) and homeland security issues such as the likelihood of the swift transport of contaminants out of a city.

Salt Lake City, Utah (SLC) lies in the northeast quadrant of a basin bounded by mountain ranges to the west, south, and east, and the Great Salt Lake to the north (Fig. 1). The wind flow in this basin has a diurnal cycle of northerly flow during the day and southerly flow at night. The simplicity of this cycle is often altered at night by canyon outflows and downslope flows from the bounding mountain ranges. The diurnal cycle and terrain-induced flows tend to form under weak synoptic-scale pressure gradients. On the scale of the SLC basin, a strong nighttime southerly jet dominates the locally forced basin-scale winds (Banta et al. 2002).

The Department of Energy's (DOE) Vertical Transport and Mixing (VTMX) field campaign of October 2000 (Doran et al. 2002) was designed to obtain meteorological measurements in the SLC basin well beyond the scope of the traditional surface meteorological network already established in the basin (Horel et al. 2002). The purpose of VTMX was to investigate how these complex wind systems in the basin contribute to the formation or destruction of the cold pool that forms in the basin in the late fall and winter months. In conjunction with the VTMX campaign was a second field campaign, the DOE's Chemical Biological National Security Program's (CBNP) Urban 2000 experiment (Allwine et al. 2002). The primary purpose of this experiment was to provide data for evaluating and improving atmospheric models for simulating toxic agent dispersal from potential terrorist activities in urban environments. As a part of the URBAN 2000 experiment, SF_6 tracer was released in the SLC downtown area during the night, to be detected by a dense array of sensors downtown, plus three arcs of samplers placed 2 km apart, beginning 2 km from the city.

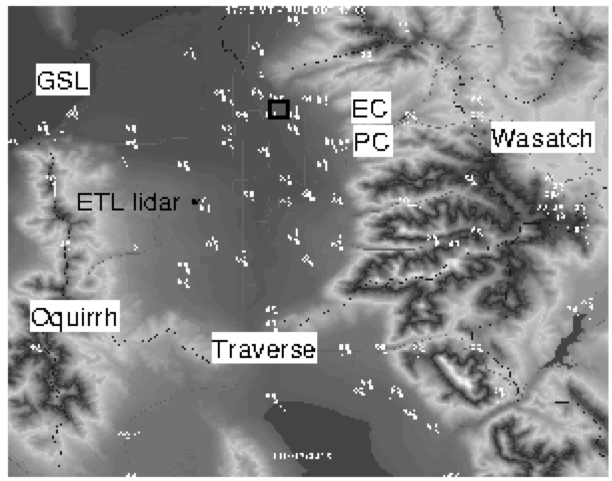

Figure 1: Map of SLC basin, adapted from a MesoWest map (Horel et al. 2002) from 17 October 2000, 2315 UTC (IOP 7). Locations of the Great Salt Lake (GSL), Emigration Canyon (EC), Parley's Canyon (PC), and the ETL Doppler lidar (*) are shown. The bold box indicates the approximate location of the downtown sampling array.

Ten Intensive Operating Periods (IOPs) were designated during VTMX. The Environmental Technology Laboratory's (ETL) Doppler lidar measurements documented the basin-scale winds and the presence or absence of local terrain-generated flows for nine of the IOPs. The SF_6 tracer releases (6 IOPs total) indicated how fast the tracer was advected out of the city, and in what direction. The three IOPs presented here will show very different scenarios

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regarding the behavior of the tracer.

2. Downtown SF_6 Tracer

There were three downtown SF_6 releases per IOP. The first release started at midnight, with a continuous release of 1 g s^{-1} for one hour, then stopped at 0100 MST for one hour. The second release began at 0200 MST, and this pattern of starting and stopping the release alternated until the third and final release from 0400 to 0500 MST. Sampling began at midnight and did not stop until one hour after the last release ended (0600 MST). Half-hour-average concentrations of SF_6 sampled during one of the releases, and the hour after it, are shown in Fig. 2 for the three IOPs.

During IOP 10 (October 26, 2000) the tracer was advected to the north or northwest of SLC during and after the release (Fig. 2a), with very small amounts (small both in concentration, < 30 ppt, and areal coverage) of the tracer remaining in downtown SLC in the last half-hour of sampling (0530 - 0600 MST). The preceding 2 releases (not shown), which started at midnight and 0200 MST, had similar behavior, with less tracer remaining downtown with each subsequent release.

The tracer dispersion pattern for IOP 7 (October 18, 2000, Fig. 2b) was in stark contrast to what was seen during IOP 10. Although the downtown concentrations weakened somewhat with time after each release, in the last hour of sampling, concentrations of at least 300 ppt of SF_6 remained in the downtown area, with a plume of tracer extending out to the edge of the sampler array. The case was also similar for the preceding two releases on this night (not shown). The tracer pattern in the first panel of Fig. 2b shows the remnants of the previous release still on the northern edge of the sampling grid during IOP 7. However, during IOP 10 (Fig. 2a) the tracer from the previous releases advected from the sampling grid

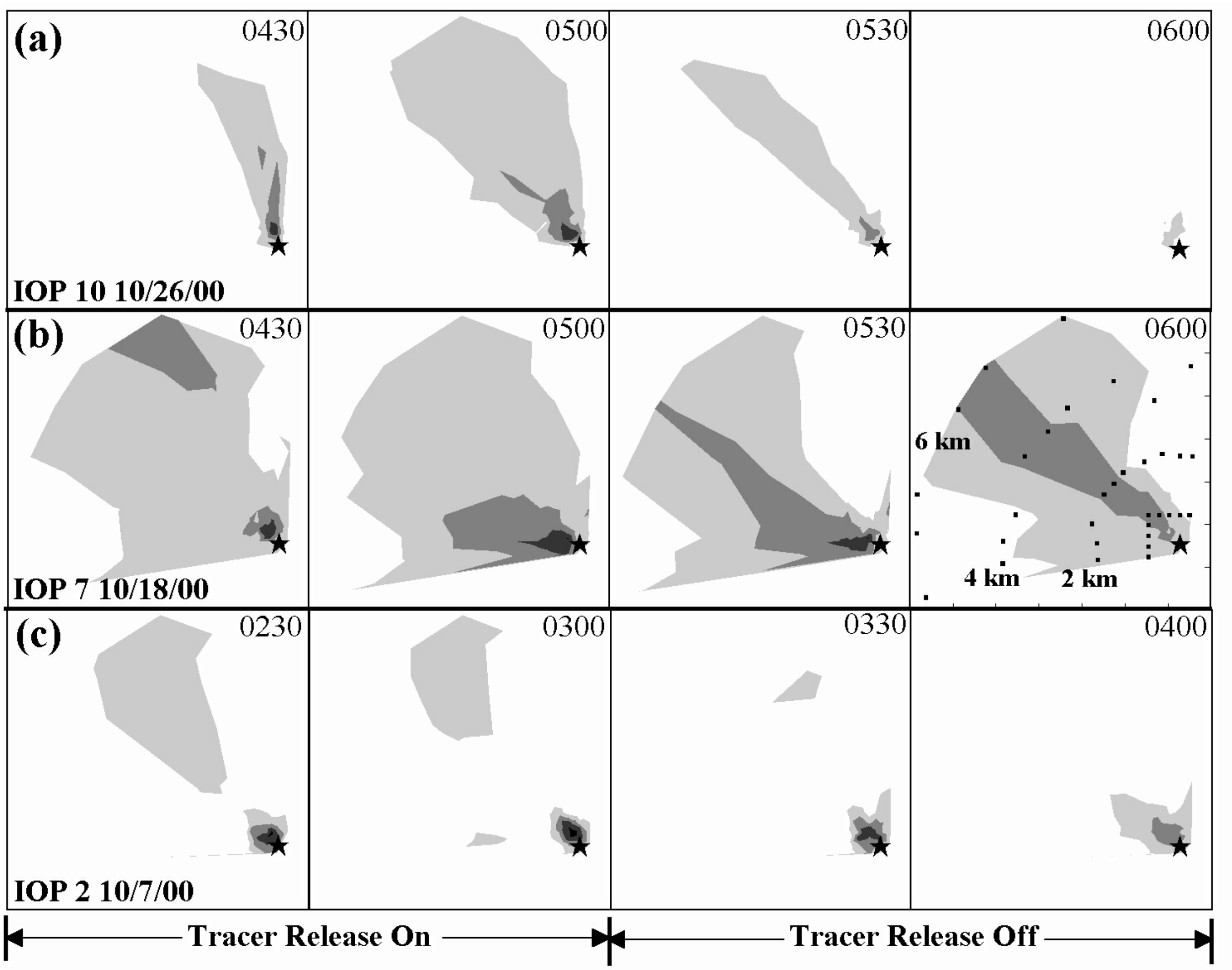

Figure 2: Half-hourly averages of SF_6 tracer measured by a network of samplers located in and near downtown SLC for a) IOP 10, b) IOP 7, and c) IOP 2. Each block of the figure represents one half-hour, with the ending time of the half-hour noted in the respective block. Tracer was released only during the first hour, from the site marked by the star. The northern and western boundaries of the downtown sampler array are indicated by the dots closest to the release site in the final panel of b). The position of the samplers in the arcs 2, 4, and 6 km from downtown are also marked by dots. The shading intervals (lightest to darkest) represent 30, 300, and 3000 ppt, respectively, of SF_6 detected.

before the start of the 0400 MST tracer release.

The tracer patterns during IOP 2 (October 7, 2000, Fig. 2c) are significantly different from either IOP 10 or IOP 7. The second of the three tracer releases during IOP 2 is shown in Fig. 2c, where remnants of the first release are seen to the northwest of the release site, persisting through 0330 MST (third panel in Fig. 2c). Throughout the second release, the tracer primarily remained downtown (> 3000 ppt concentrations) with a slight movement easterly as detected by mobile tracer analyzers driven around the downtown area. After the second release and before the start of the third release, the tracer again began moving slowly to the northwest (fourth panel in Fig. 2c), but was primarily confined to within two km of the downtown area.

3. Doppler lidar data

In Fig. 3 we present constant-elevation-angle scans of Doppler lidar radial velocities. The fixed elevation angle was 1.5 °, therefore, with distance from the lidar the heights of measurements gradually increased. The start times of these scans approximately correspond in time to the stop time of the tracer releases shown in Fig. 2, indicating the structure of the basin-scale winds when the releases stopped. During IOP 10 (Fig. 3a) Doppler lidar radial velocities indicated southerly flow. The radial velocity zero line, which here is perpendicular to the flow, is a straight line, implying that the winds were from the south at all heights measured with this scan (~30 m to ~260 m above the lidar).

In contrast, lidar measurements from IOP 7 (Fig. 3b) indicated southerly flow closer to the surface with an abrupt switch to easterly flow ~ 80 m above the height of the lidar (note the sharp bend in the zero line ~ 3 km east of the lidar). The easterly flow was associated with the canyons and sloping terrain bounding the east side of the basin. The presence of this easterly flow indicated that conditions on this night were conducive to the formation of local circulations, such as slope flows and canyon outflows (supported by many other Doppler lidar scans and surface meteorological observations, not shown).

During IOP 2 we had stronger atmospheric signal, i.e., more range, with the Doppler lidar, so the lidar scan shown in Fig. 3c is smaller in size in order to show the data to nearly 20 km range. Compared to IOPs 7 and 10, the winds in the center of the basin were much weaker. Strong canyon outflows from Emigration and Parley's canyons (streamers of stronger wind to the northeast of the lidar) were measured. These outflows were a result of the channeling of easterly synoptic flow. At this time, mesonet observations (not shown) measured weak winds at the surface, indicating that the strong channeled flow was elevated at this time.

4. Conclusions

During IOP 10, the synoptically-driven basin-scale winds dominated and local-scale terrain-generated flows existed only briefly and intermittently. The uniform southerly winds throughout the basin encompassed the downtown SLC area and enhanced the tracer transport out of the city, toward the north and northwest.

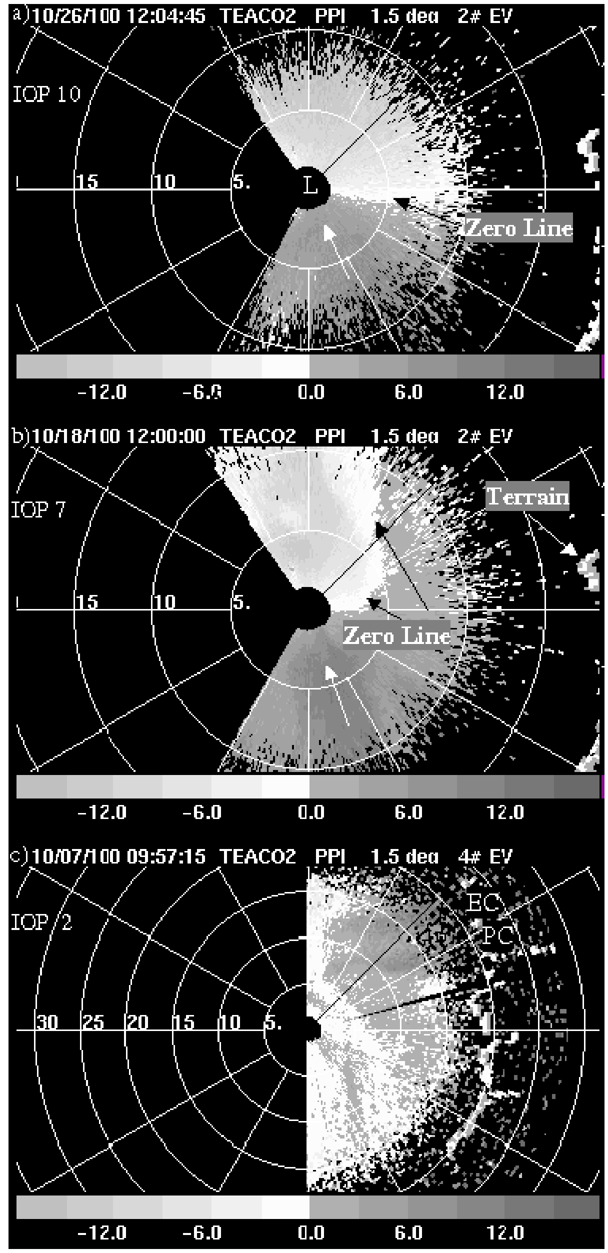

Figure 3: ETL Doppler lidar radial velocity measurements corresponding to the approximate ending times for the tracer releases shown in Fig. 2. The lidar is in the middle of each plot, indicated by an 'L' in a); data was taken in a cone, 1.5° above the horizon. North is to the top. The range rings are in 5 km increments (note that more range is shown in c). Darker shades of gray (positive velocities) indicate flow toward the lidar while lighter shades of gray (negative velocities) indicate flow away from the lidar (white arrows are directional reminders). Times are the start times of the scan in UTC (UTC - 7 = MST). 'EC' represents the approximate opening of Emigration Canyon, and 'PC' marks the approximate opening of Parley's Canyon. a) IOP 10; b) IOP 7; and c) IOP 2.

Lidar data indicated the presence of local-scale terrain-induced circulations during IOP 7. These flows included canyon outflows and slope flows on the east side of the basin. Inspection of the local surface mesonet stations (not shown) indicated light east-southeasterly winds, with small horizontal eddies forming at times, in downtown SLC during the time of tracer sampling. As a result, the tracer primarily lingered in the downtown area, but slowly moved out of SLC to the west-northwest.

The synoptically-driven easterly winds that flowed over the Wasatch Range during IOP 2 resulted in strong downslope (easterly) flow into the basin, but this flow did not reach the surface until the end of the sampling period. Local circulations formed at the surface such that the core of highest concentrations was confined to the downtown area.

Further investigations into the tracer behavior will involve assessing the winds above the surface, as measured by the Doppler lidar, and coordinating with mesoscale modelers who are using modeled winds to infer convergence and vertical motion in the basin (e.g., Fast et al. 2002). In turn, Doppler lidar data can be used by mesoscale modelers to assess how well their simulations are capturing the complex winds in the SLC basin.

5. Acknowledgments

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