8.4 THE INFLUENCE OF SYNOPTIC CONDITIONS ON FLOW BETWEEN MOUNTAIN BASINS

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1. INTRODUCTION

Increased population and industry in the Intermountain West has multiplied air pollution sources and has lead to degraded air quality. Vertical mixing influences air quality by contributing to the dilution of pollutants, but it is poorly understood, particularly in the stable atmospheric boundary layer. Thus, one goal of the Vertical Transport and MiXing (VTMX) program (Doran et al., 2002) is to investigate the meteorological factors and processes that contribute to vertical mixing, or the suppression of mixing, in stable atmospheric boundary layers, particularly for urban areas located within complex terrain.

The Salt Lake City basin is one of a number of broad valleys, in northern Utah. It opens to the Great Salt Lake on the north and Traverse Mountains divide it from the Utah Lake basin and the Cedar Valley to the south. Figure 1 presents the topography and major land features in this region. The elevations range from approximately 1250 m near the Great Salt Lake to more than 3300 m on some of the peaks of the Wasatch Front. The Salt Lake City basin was the location of the Vertical Transport and Mixing (VTMX) program field experiment in October of 2000, and it is an area that has experienced urban air quality problems.

During the experiment's ten Intensive Observation Periods (IOPs), flow through the Jordan Narrows, a gap in the Traverse Range, was found to be significant, in addition to the known night time drainage from canyons that enter the valley from the east. Stewart et al. (2002), in an analysis of surface mesonet observations, has documented this nocturnal flow through the Jordan Narrows under weak synoptic influences, as well as similar flow between the Tooele and Rush Valleys, just to the west. Stone et al. (1989, 1990) also documented flow between the Tooele and Rush Valleys. Their study indicated additional flows, through the series of passes that separate Rush Valley and Cedar Valley to its east.

Doppler Lidar observations during the VTMX field experiment, reported by Banta and Darby (2002), noted a distinct difference in the nature of the down-valley flow that was present during each of the IOPs. They observed that the down-valley flow originated from the direction of the Jordan Narrows. However, on the night of 17-18 October (IOP7) this down-valley flow developed earlier and became stronger than on the night of 19-20 October (IOP8).

In an attempt to better understand the flow observed by the doppler lidar and the circulations within the Salt Lake City basin, numerical simulations of two IOPs are presented. The discussion will focus on how the circulations and vertical mixing within the Salt Lake City basin are influenced by flows that enter or exit the basin from nearby basins and by drainage flows from the canyons that enter the valley from the east. We document two similar cases to investigate the role of synoptic weather conditions in this exchange of air in the Salt Lake City basin. In particular, we explore the hypothesis that synoptic conditions influence the strength of the down valley flow through the Jordan Narrows and its interaction with the canyon outflows and therefore influence the nature of the vertical transport and mixing.

2. SYNOPTIC CONDITIONS

IOPs 7 and 8 (the nights of 17-18 and 19-20 October 2000) of the VTMX field experiment are the focus of this paper. These two nights experienced similar, but somewhat different synoptic conditions, particularly early in the IOPs, which began near sunset. Analysis of the 0000 UTC synoptic fields at 500 mb indicates that both IOPs begin under the influence of an upper level pressure ridge.

In the case of IOP7, the 0000 UTC height field on 18 October indicates that the ridge axis is just east of Salt Lake City (SLC), through western Wyoming and central Montana. By 1200 UTC on the 18th, the ridge progresses eastward, with its axis in central Wyoming and eastern Montana. Winds at this level change from 5 ms^{-1} southeasterly to 10 ms^{-1} southwesterly, over the 12 hour period.

For IOP8, the height field on 20 October shows that the upper level flow at SLC is transitioning from a short wave trough to a shorter wavelength (compared to 18 Oct.) ridge. The axis of the ridge is in western Idaho at 0000 UTC and over the SLC area at 1200 UTC. Winds

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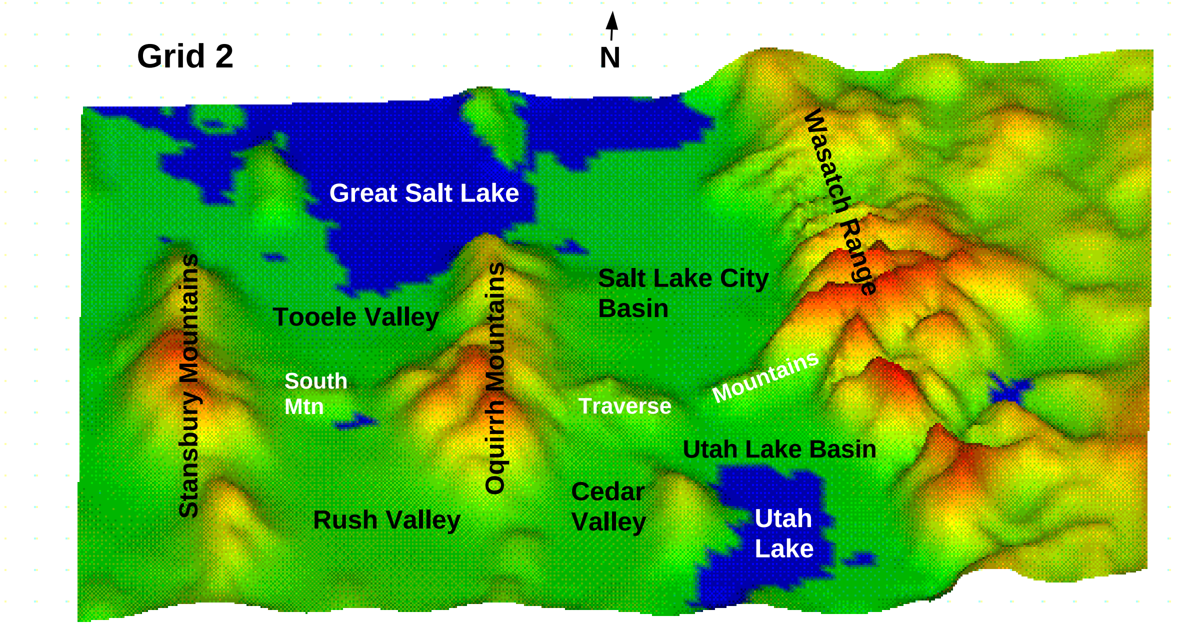

Figure 1. Topography and land features in the Salt Lake City region as depicted on RAMS grid 2.

at 500 mb are northwesterly and decrease from 18 ms^{-1} to 5 ms^{-1} during IOP8.

Surface analyses for both nights show that the area is under the influence of relatively high pressure, between weather systems that are along the west coast and in the upper midwest. This high pressure is stronger on 18 October and continues to strengthen through the night, particularly to the south and east of the SLC area. Surface pressures also rise during the night of 20 October, but the highest pressures are to the north and east of the SLC area.

The differences in the ambient weather conditions stand out more in the 0000 UTC soundings from the SLC airport rawinsondes. The surface temperature at the start of IOP8 is warmer than for IOP7, with the static stability at the start of IOP7 significantly stronger than the static stability of IOP8, particularly in the levels between roughly 850 mb and 600 mb. These pressure levels correspond to a vertical layer that extends from a few hundred meters above the surface (within the basin) to well above the mountain tops. The sounding surface winds report northerly (up-valley) flow at 0000 UTC for both IOPs, but ridgetop winds are light and easterly, becoming westerly further aloft, on 17 October. Ridgetop winds are moderate and westerly on 20 October, turning through northwesterly to northerly at higher levels.

3. MODEL SIMULATIONS

Simulations of IOPs 7 and 8 of the VTMX field experiment are produced with the Regional Atmospheric Modeling System (RAMS) model (Pielke, et al., 1992). The RAMS model has also been applied to the Salt Lake City basin in Zhong and Fast (2003) and Fast and Darby (2004). In this study, three nested grids are used in order to simulate regional to local scale flows, with horizontal grid spacings of 3.6 km, 1.2 km, and 400 m. Grid 1 covers northern Utah. The second grid includes the Salt Lake City basin and the surrounding valleys and mountains, and grid 3 focuses on the Salt Lake City basin, including the Wasatch Mountains and the northern portions of Utah Lake basin. Vertical grid spacing is a constant 10 m for the lowest levels. Above 60 m, vertical grid spacing is slowly stretched until the maximum grid spacing of 600 m is reached. At that height, the vertical grid spacing is again held constant to the top of the domain, at just under 14 km.

The simulations begin at 0000 UTC 17 October, for IOP7, and 19 October, for IOP8. Each simulation runs for 42 hours. The runs are initialized and nudged using NCEP Reanalyis II gridded fields. They are used here to represent the synoptic weather patterns at the initialization and the nudging introduces the changes in those large-scale fields that occur during the course of each of the IOPs. The simulations continue for 24 hours before the start of the IOPs, to allow the model to generate regional and local flows that are induced by the complex terrain and surface heterogeneities, but are not captured in the Reanalyis fields. Water temperature is initialized as 287 K, based on the mean of observed water temperatures from Mesowest (Horel et al., 2002) records.

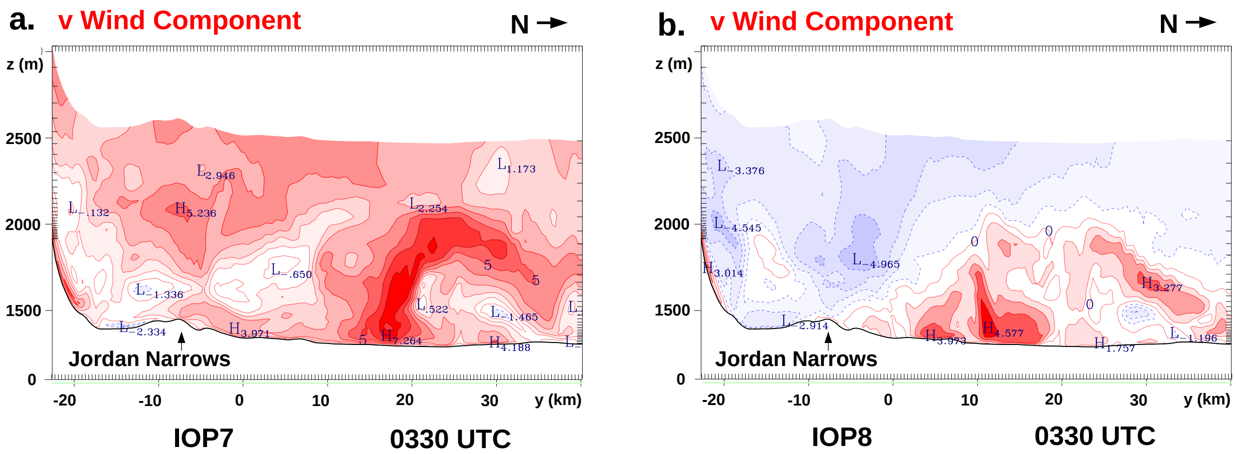

Figure 2. Vertical cross-sections of v wind component on RAMS grid 3 at 0330 UTC for a) IOP7 and b) IOP8. Red shading depicts positive values and blue shading depicts negative values. Contour interval is 1 ms^{-1}.

4. RESULTS

The model results agree with the observations by producing stronger and earlier down-valley (southerly) flow through the Jordan Narrows during IOP 7 than during IOP 8. On both nights, the daytime up-valley flow dies down shortly after sunset and down-slope flows develop on the steeper slopes of the Wasatch, Traverse, and Oquirrh Mountains. Drainage flows from the canyons to the west also contribute to cooler air that drains northward out of the basin toward the Great Salt Lake at the open end of the valley. At the same time, slope flows and canyon drainages from the Wasatch Mountains also contribute cooler air to the Utah Lake Basin, south of the Jordan Narrows. Eventually, air from the Utah Lake basin flows through the Jordan Narrows and over the Traverse Mountains into the Salt Lake City basin.

Figure 2 presents vertical cross sections of grid 3 at 0330 UTC for IOP7 (Figure 2a) and IOP8 (Figure 2b) running from northern part of the Utah Lake basin (on the left side of the figure), through the Jordan Narrows (at y=-8 km) and the Salt Lake City basin. Southerly flow is present through the Narrows and the Salt Lake City basin during IOP 7, with southerly flow extending above the surface and reinforced by the surface pressure gradient. The down valley flow of IOP8 is not fully established and confined to areas north of the Jordan Narrows, where canyon outflows turn down-gradient after exiting the confines of the canyons. Above the surface, winds are northerly, counter to down-valley flows.

By 0930 UTC, southerly, down-valley winds, are found on both nights in the Salt Lake City basin, but flow through the Jordan Narrows is better defined during IOP7. Vertical cross sections of potential temperature and winds (Figure 3) indicate the presence of gravity waves at that time. These waves serve to enhance the down-valley flow during IOP7. Vertical motions associated with the gravity wave are stronger for IOP7 (Figure 4), when stronger winds crossing the Traverse Mountains and greater static stability contribute to more favor-

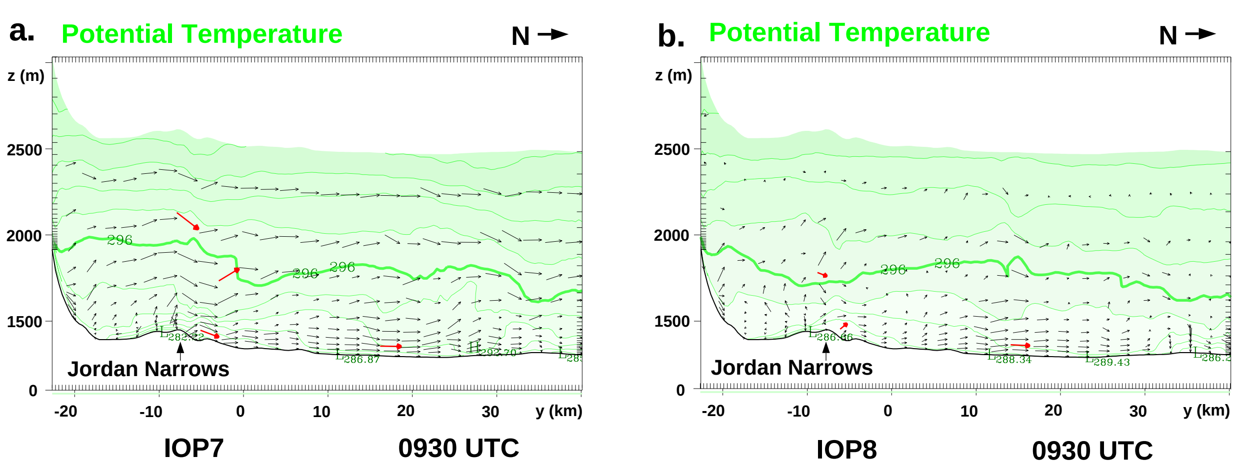

Figure 3. Vertical cross-sections of potential temperature and winds on RAMS grid 3 at 0930 UTC for a) IOP7 and b) IOP8. Contour interval is 1 ^{o}C.

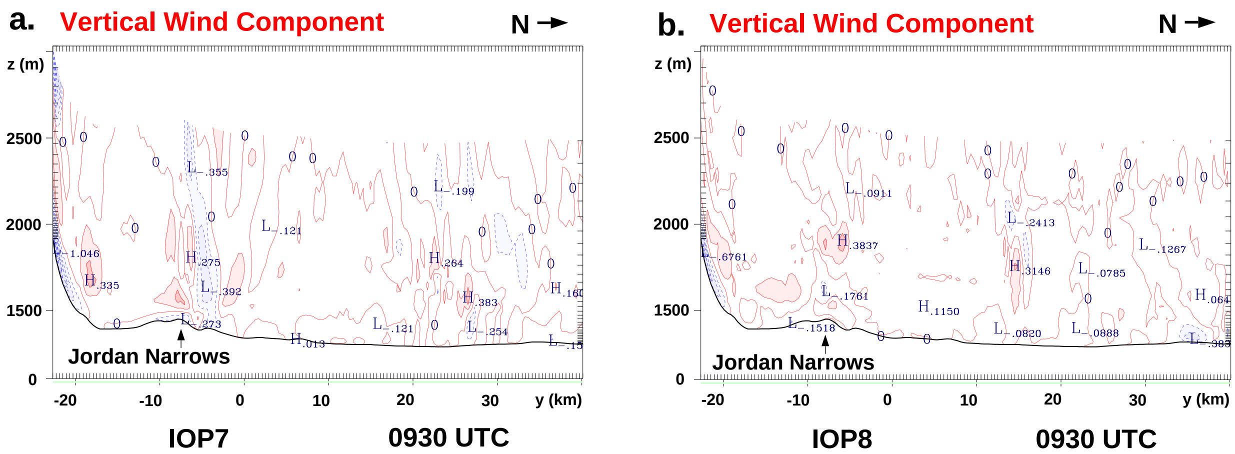

Figure 4. Vertical cross-sections of w wind component on RAMS grid 3 at 0930 UTC for a) IOP7 and b) IOP8. Red depicts ascending motions and blue depicts decending motions. Contour interval is 0.15 ms^{-1}.

able conditions for larger amplitude waves with greater vertical motions.

The strength and the timing of the canyon outflows were also different during the two IOPs. This suggests that they are also influenced by synoptic conditions. The down-valley flow converges with the canyon outflows earlier in the simulation of IOP7, producing localized areas of vertical motion in the Salt Lake City basin, earlier in the evening. Horizontal cross sections of the wind field for a portion of grid 3 is shown in Figure 5. The locations of two observational sites are marked by plus signs. The Doppler Lidar operated by the National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL), in the center of the valley, and the site operated by the National Center for Atmospheric Research (NCAR), near the Jordan Narrows, are given for reference. At 0930 UTC, The winds for IOP7 are more organized in a down-valley flow from the Jordan Narrows than IOP8, particularly near the narrows. Flow from the east at y=6 km, is outflow from Little Cottonwood Canyon that converges with the down valley flow. Vertical velocities for the same horizontal cross sections indicate areas of upward motion, where the

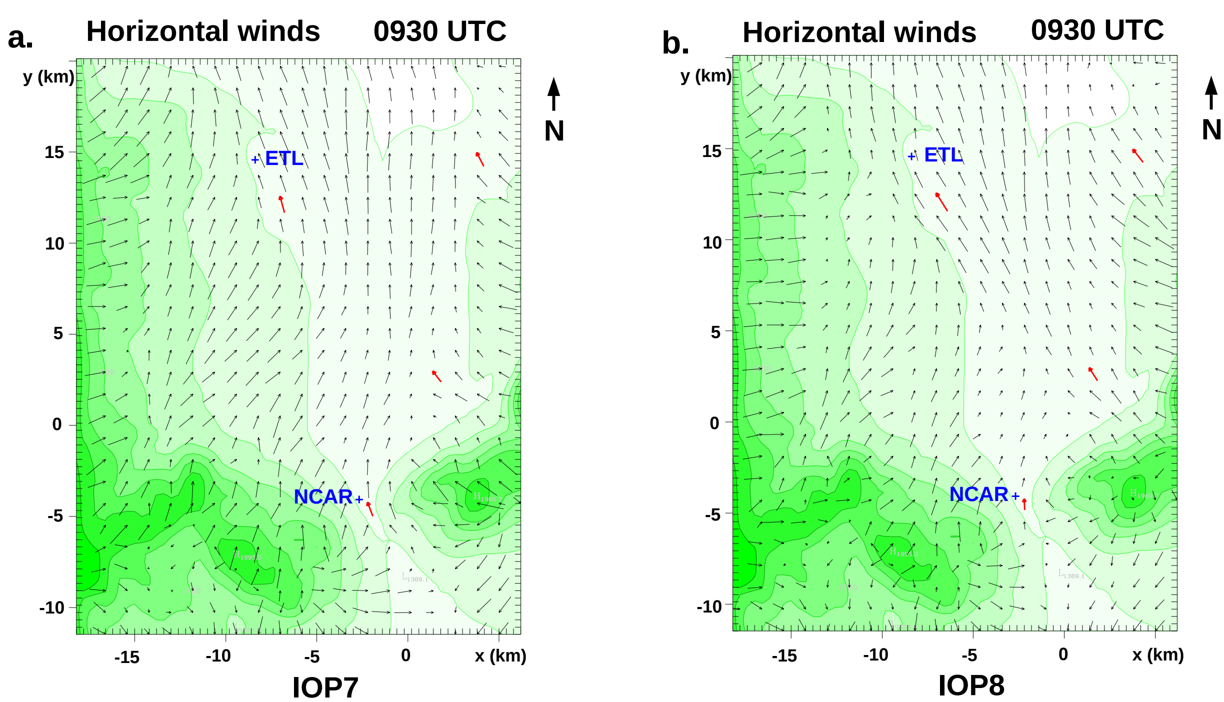

Figure 5. Horizontal cross-sections, at 15 m AGL, of winds on part of RAMS grid 3 at 0930 UTC for a) IOP7 and b) IOP8. Green shading indicates topography in the vicinity of the Traverse Mountains. Contour interval is 100 m. ETL is the location of the Doppler Lidar and NCAR is the location of the NCAR observations.

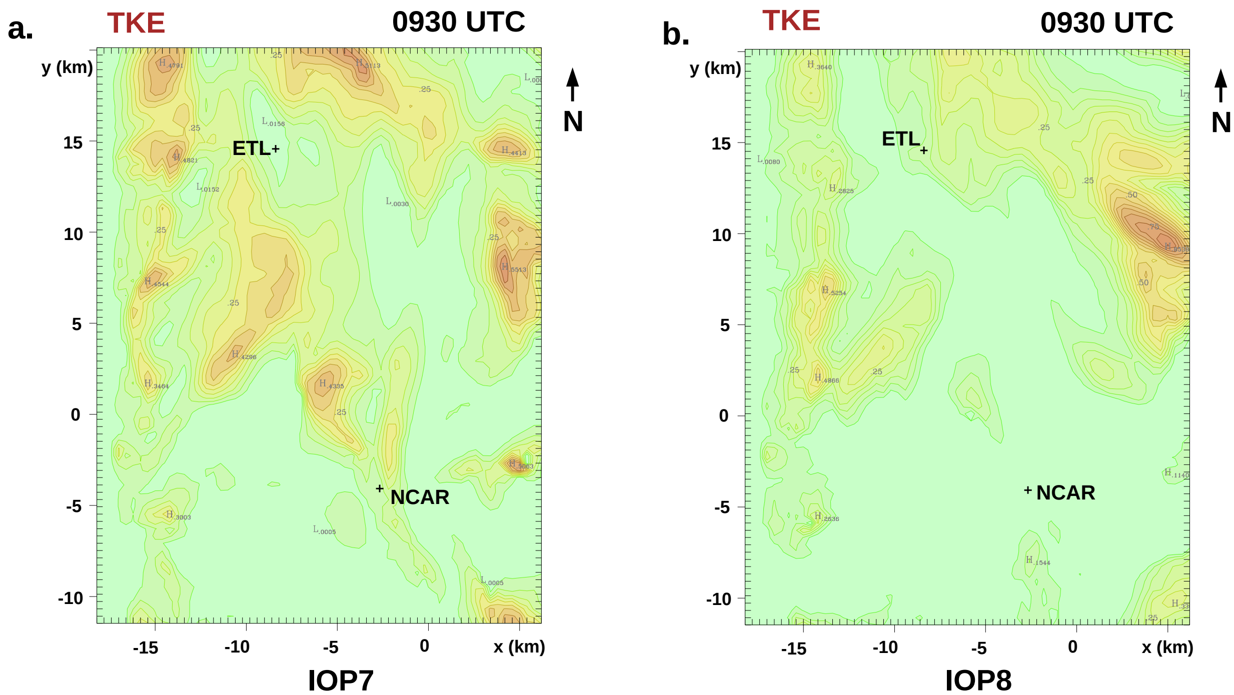

Figure 6. Horizontal cross-sections, at 15 m AGL, of sub-grid turbulent kinetic energy on part of RAMS grid 3 at 0930 UTC for a) IOP7 and b) IOP8. Contour interval is 0.05 m^2s^{-2}. ETL is the location of the Doppler Lidar and NCAR is the location of the NCAR observations.

flows converge, that can contribute to vertical mixing. Subgrid Turbulent Kinetic Energy (TKE) fields (Figure 6) indicate significant differences between the two nights at the 15 m AGL level. While TKE is generally small at night, both simulations have significant TKE associated with the canyon outflow. However, IOP7 also has areas of enhanced TKE in the center of the basin, associated with the down-valley flow through the Jordan Narrows.

By just before sunrise, when synoptic conditions between the two IOPs are most similar, both simulations showed down-valley flow in the basin, converging with the canyon outflows, but the locations of the associated vertical motions are somewhat different and the magnitudes are much larger for IOP 7.

5. SUMMARY

The model results indicate that the differences in large-scale weather for the two IOPs can affect the flow through the Jordan Narrows. During IOP7, upper level winds and pressure gradients supported earlier and stronger southerly flow through the Jordan Narrows, compared to IOP8. The synoptic conditions also lead to a more favorable environment for the formation of gravity waves as air passed over the Traverse Mountains during IOP7. The higher wind speeds in the down valley flow on IOP7 are associated with greater TKE and suggest that vertical mixing would be more likely in the center of the basin on that night.

Drainage flows from the canyons in the Wasatch Mountains can be found in both the Utah Lake and Salt Lake City basins and they also seem to be influenced by the synoptic conditions.

6. ACKNOWLEDGMENTS

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