**P6.1** MIXING PROCESSES AND THE INTERACTION AMONG 3 ATMOSPHERIC REGIMES IN THE SALT LAKE CITY BASIN

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## 1. INTRODUCTION

During the October, 2000 Department of Energy Vertical Mixing and Transport Experiment (VTMX) in the Salt Lake City Basin (SLC Basin), a 3-regime atmospheric structure was observed by instruments deployed therein. Here, we describe a case study of IOP-10 which occurred overnight during 25-26 Oct 2000 and additional factors that influence those regimes.

The statically, and often dynamically, stable atmosphere that typically characterized this partially enclosed complex terrain basin, was found to be subject to a forcing by primarily three components, Regime I) meso-β to meso-γ scale terrain induced flows, that generally determined the surface layer characteristics and were most often responsible for low-level mixing events, Regime II) a meso-α scale basin-wide, elevated, layer, that can create shear between the surface layer and the terrain maxima surrounding the basin, and Regime III) larger-scale, terrain-influenced synoptic flows, which induced mountain wave activity at upper levels and triggered gravity waves on the basin inversion. This 3-regime structure is a context within which to evaluate vertical mixing events and subsequent pollutant transport and distribution with time. These events were appear to be caused by interaction of two or three forcing mechanisms within the 3-regime structure coinciding in space and time. Both observational and mesoscale numerical modeling results are discussed, in evaluating the three-regime structure for IOP-10 and various influences upon it.

## 2. INVESTIGATIVE PROCEDURE

The mesoscale model used here was the Regional Atmospheric Modeling System, (RAMS, Pielke et al. 1992). NCEP Eta analyses were used for initialization at 1200 UTC 25 Oct and subsequent outer model boundaries over a 24 hour simulation period. Adequate numerical prediction on small-scales requires some means by which to resolve the region of interest while not sacrificing the larger scales which are crucial to the dynamics of the three scales within the Basin three-regime structure. Thus, multiple nested grids were employed.

Grid 1 (24 km grid spacing over 140 x 140 grid points) encompasses the western U.S. to capture details of the synoptic evolution. Grid 2 (6 km grid spacing over 82 x 90 grid points) covers the area of Northern Utah, while Grid 3 (1.5 km spacing over 82 x 82 grid points) captures the immediate vicinity of the Salt Lake City Basin, where the densest VTMX observations were taken (Figures 1 and 2). Vertical grid spacing was a constant 45 m at low levels, stretching above 360 m AGL (to a maximum 400 m vertical spacing) with a domain top at approximately 18 km.

Observations were obtained from the various VTMX investigators for comparison with modeled fields, but our focus here is on the 0600 UTC Utah Mesonet data showing surface flow features (Figure 2). In our more detailed simulations, and as more VTMX data becomes available, detailed comparisons with vertical profiles from the 4 tethersondes located in the southwest portion of the SLC Basin on the east side of the Oquirrh Mountains (see Figure 1) will be made.

## 3. RESULTS

The evolution of wind and temperature fields in the SLC Basin is complex. Figure 2 shows the Utah mesonet data for 26 Oct 2000 during IOP-10 06 UTC. Temperatures are generally warmest near the Salt Lake and in the center of the SLC Basin, the latter possibly due to an urban heat-island effect. Cooler temperatures associated with drainage flow from the Oquirrh mountains are seem on the west side of the valley, as well as an area along the eastern SLC Basin.

The observed flow is generally light, under 5 m $s^{-1}$. Evidence of a land breeze is seen near the lake and central portion of the Basin. Westerly drainage flows are seen at two stations in the southwest SLC Basin with easterly drainage at several eastern SLC Basin stations. This corresponds to katabatic flows observed by surface stations and tethersondes operated by Pacific Northwest National Lab to the east of the Oquirrh Mountains.

Surface wind and temperature at the same time from the model simulation are shown in Figure 3. The general pattern agrees well, with warmer air in the central SLC Basin and cooler air along the east and west sides of the valley. Maximum model temperatures in the middle SLC Basin are on the order of $1^oC$ too cool. Sharp temperature gradients along the SLC Basin sides mark the steeply rising topography (Figure 2).

Wind fields from the simulation (Figure 3) show evidence of the land breeze near the Salt Lake and in the northern SLC Basin. Along the west side of the valley westerly drainage winds occur from the Oquirrh Mountains. However, the model westerly drainage flow continues well into the eastern SLC Basin, which does not agree with the observations. Close inspection shows that easterly drainage flow is occurring on the east side of the SLC Basin down the prominent canyons, but does not

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extend fully to the valley in agreement with the surface observations. This is shown by the region of fairly stagnant air along the eastern SLC Basin at the foothills of the Wasatch Mountains.

Figure 4 shows a north-south section of zonal wind through the Traverse Mountains Gap and the center of SLC Basin (i.e., along x = 7 km in Figure 3) at 0600 UTC. In the SLC Basin from y = -5880 to -5830 km, a 3-regime pattern is seen, with a westerly component at the lower levels, an approximately one kilometer deep easterly component, overlain by ambient southwesterly flow. At the north end of SLC Basin, an easterly component is seen up to the region of ambient southwesterlies. Potential temperature sections (not shown) indicate that this easterly flow is still associated with cold drainage flow which has formed an eddy towards the northern end of the Oquirrh Mountains (also seen in Figure 3).

The primary driver for the three Regime system shown in Figure 4 is the orography surrounding the SLC Basin. The barrier surrounding SLC has a relief of approximately 1500 m from the Basin floor (~ 3000 m AGL). This barrier creates an environment where surface-driven, terrain-induced flows are common (anabatic and katabatic flows), or Regime I. Additionally, the terrain around the basin is highest on the east and west sides, with Traverse Mountain Gap to the south. This orientation creates a channeling effect depending on the synoptic pressure gradient, such as described by Whiteman and Doran (1993), and Regime II. Regime II dominates the Basin atmosphere to capping inversion height. Finally, Regime III is characterized by the synoptic winds aloft which, 1) more nearly geostrophic, 2) interact to create mountain waves at barrier crest, and 3) can impact Regime II (or via mixing Regime I as well). Each of these 3 Regimes can, by nature of their difference forcing mechanisms (radiative cooling, channeling and geostrophy), create directional and speed shear with the adjacent Regime, and influence vertical mixing.

The evaluation of the three regime structure of the SLC Basin is complicated by a variety of additional features, some of which are rare in mountainous regions where the three Regime system may otherwise apply. These are (see Figure 1):

1) the Salt Lake to the northwest
2) the urban center in the north
3) the Traverse Mountains Gap to the south and the Provo Valley further south
4) the west facing canyons on the east side.

First, the Salt Lake itself creates a mechanism for alternate forcing of Regime I near the surface and can counter some of the straightforward forcing of Regime II (channeling). During October the lake is warmer overnight, on average creating a land breeze circulation (as notable in Figures 2 and 3). Nocturnally (and sometimes during daytime in winter) this condition is prevalent October through April because the Salt Lake is saline which prevents freezing. Thus, the Salt Lake is also a source of moisture flux throughout the year, which can increase the likelihood of haze in stable atmospheric conditions.

Another complicating factor is the significant urban center of Salt Lake City. This area can create a heat-island and associated wind convergence upon itself, due to upward vertical motion and locally lower pressure. This could a focal point for vertical transport of scalars. This effect was not indicated strongly in our simulation of IOP-10, possibly due to the mischaracterization of land use characteristics of the urban center.

The Traverse Mountains Gap (see Figure 1) acts somewhat like a 'relief valve' for differential pressure between the SLC Basin and the Provo Valley to the south. During IOP-10 our numerical model results indicate that for ~ 6 hours, after the Provo Valley became cooler than the SLC Basin that flows developed from the south to the north through the Gap (not shown).

Finally, large canyons exit through the foothills of the Wasatch Mountains on the west side of the valley. At times, katabatic flows can exit these canyons (e.g. Big Cottonwood) and create directional shear within the Basin atmosphere overnight (Regime II). Depending on the potential temperature near the surface in the Basin, these flows may penetrate into Regime I, or like in IOP-10, see Figures 2 and 3, remain aloft. In our numerical study, inadequate resolution of the topography in these canyons may underestimate the impact of this factor. The relatively larger relief of this barrier compared to the Oquirrh Mountains on the east side of the Basin may also be significant.

## 4. SUMMARY AND FUTURE WORK

We have found that a three-regime structure develops in the SLC Basin during the October 2000 DOE VTMX field experiment (IOP-10). This structure is influenced by a variety of factors unique to this urban Basin, creating significant challenges in evaluating vertical transport and mixing therein. As data from the VTMX field study becomes increasingly available we will use that information to further validate our simulations and the various impacts on this structure. We believe this can be a useful context within which the vertical transport and mixing within the SLC Basin can be evaluated.

Ongoing work is underway with significantly more detailed numerical simulations ($\Delta x = \Delta y = 500$ m, $\Delta z = 15$ m), allowing for better resolution of potentially significant atmospheric phenomena.

## 5. ACKNOWLEDGMENTS

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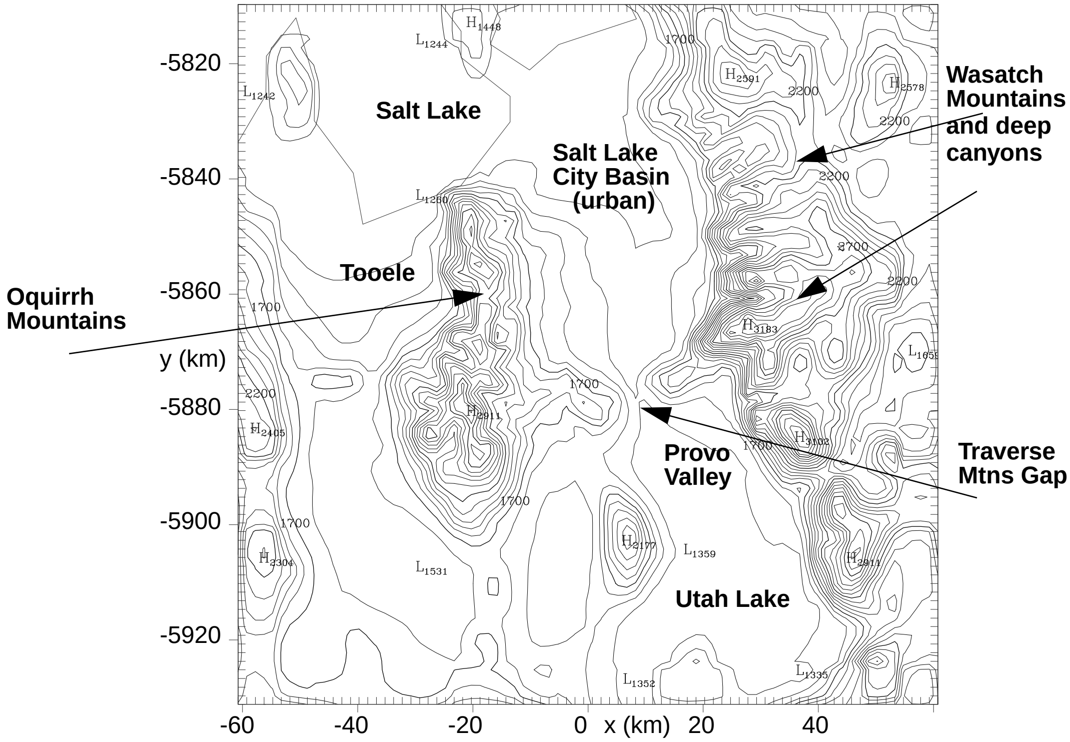


Figure 1. Grid 3 topography (100 m contours) as represented in RAMS for the simulation of IOP-10 from the VTMX field experiment. Note the various important physiographic features that complicate SLC Basin flows.

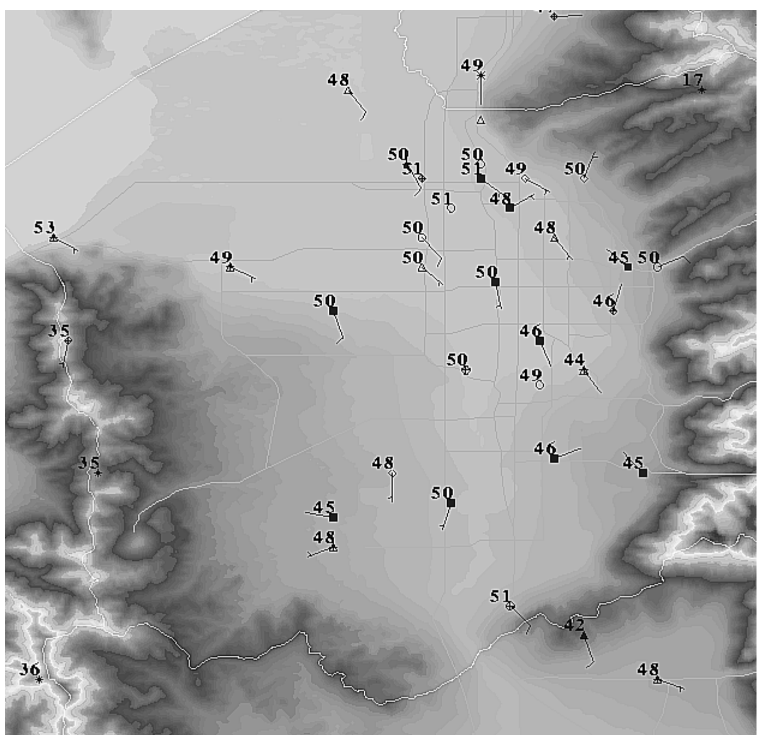

Figure 2. Observations of temperature ($^{0}$F) and winds (full barb = 5 m s$^{-1}$) from the Utah Mesonet at 0600 UTC 26 Oct 2000 for comparison with Figure 3. Note the easterly flow on the west side of the Basin, the relatively weak, variable flow along the east side of the Basin (along the Foothills of the Wasatch Mountains), the flow through Traverse Mountains Gap and the turning of the flow toward the Salt Lake on the northern end of the Basin.

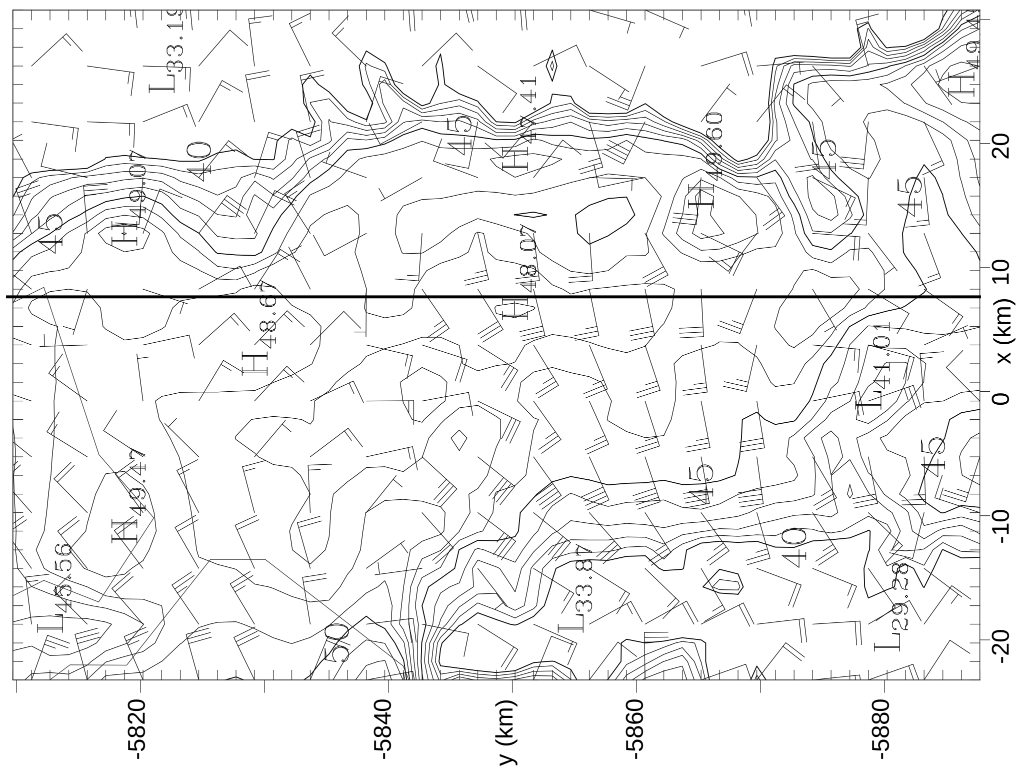


Figure 3. 20m AGL winds (each full barb = 2 m $s^{-1}$) and temperature ($1^{o}$F increments) from Grid 3 over the Salt Lake City Basin during IOP-10 at 0600 UTC 26 Oct 2000. Note westerly flow on the west side of the Basin, weak winds along the Wasatch Mountains, and the winds toward Salt Lake. Compare to Figure 2.

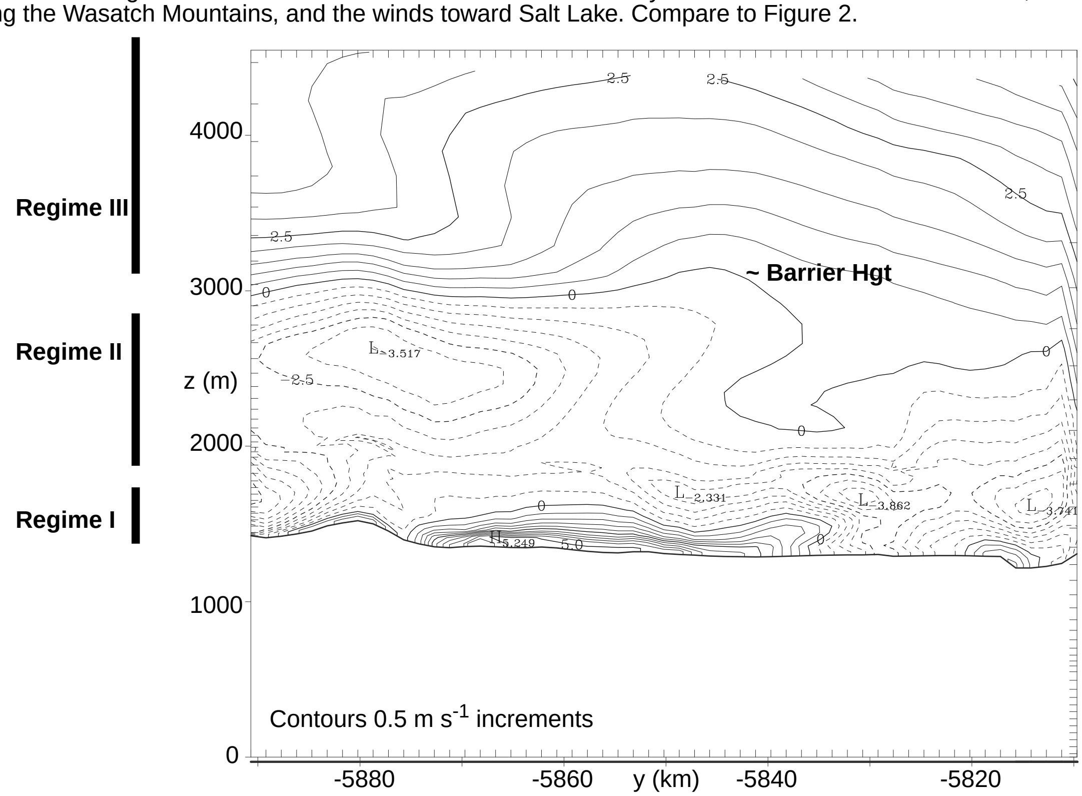


Figure 4. A vertical cross-section of u-component wind along the line indicated in Figure 3. Note the 3-regime structure of the Basin; Regime I: near the surface; Regime II from Regime I: to near barrier height; Regime III: ambient flow.