P1.10 OBSERVATIONS OF THE METEOROLOGY OF TWO NEVADA BASINS

Stephen A. Cohn*[1], John Hallett[2], John Lewis[3], and William O.J. Brown[1]
[1] National Center for Atmospheric Research, Boulder, CO, USA
[2] University of Nevada, Reno and Desert Research Institute, Reno, NV, USA
[3] Desert Research Institute, Reno, NV, and National Severe Storms Laboratory, Norman, OK, USA

1. INTRODUCTION

During four weeks of February and March, 2002, two NCAR Integrated Sounding Systems (ISS) were deployed in western Nevada - one in the Reno basin just south of Huffaker Hills, and the other in the Washoe basin just west of Washoe Lake.

The ISS measures winds, thermodynamics and radiation near the ground, monitors profiles of wind and temperature to several kilometers with a radar wind profiler, and extends these profiles as high as 15 km using balloon-borne radiosondes.

The deployment was part of an educational project organized by the University of Nevada, Reno and the Desert Research Institute. Students in ATMS 478, a required graduate level class in the atmospheric science program, studied the ISS instruments as the instruments monitored the atmosphere. The scientific goal of the deployment was to study several meteorological processes and how they differ in the two basins. These processes include the formation, evolution, and break-up of inversions which trap pollutants near the surface, the influence of the basins on winter fronts moving over and around the Sierra, high wind speed events which generate waves and turbulence at mountain top altitudes, and processes in the melting layer where snow aloft melts into rain.

The weather during the four weeks was richly varied, and we made measurements addressing each goal. In this paper, we present ongoing research into several particularly interesting events studied by scientists and students in the class.

2. KATABATIC FLOWS

Surface measurements at the Reno basin site included a transportable DRI tower with wind measured at 1.0 m, 2.1 m, and 4.7 m, and the NCAR ISS tower with a wind measurement at 10.0 m. Temperature was measured at 1.1 m, 3.9 m, and 8.0 m on the DRI tower, and at 2.0 m on the NCAR tower. Relative humidity was also measured at 1.1 m on the DRI tower and at 2.0 m on the NCAR tower. These intervals were chosen to provide equal logarithmic spacing.

The Reno site was located near a low point of the basin and not far from the mountains of the Carson Range to the east, and the small Huffaker Hills to the north. On nights with stable stratification of lower level air, drainage flows were observed by the surface instruments, and on several nights these flows appeared as periodic pulses of cold air. Knowledge of the periodicity of katabatic flows is of particular interest, for example, in forecasting the minimum temperature in a local frost hollow. The best condition for low surface temperatures is a complete lack of air motion, as colder and drier air settles within a hollow. A drainage flow can be expected to disrupt the local stratified air, mixing warmer air down to the surface. On the other hand, the drainage flow will also bring air with different properties, which could be cooler than the local air.

The minimum wind speed detectable using the propeller-vane anemometers was about 0.5 m/s. Slower speeds are not measured because of friction in the anemometer. However, lower velocities were detected (and indeed measured) by generating and tracking soap bubbles. This was done as part of the class research into atmospheric measurements. When bubbles are produced and they fall straight down, wind velocity is less than 0.05 m/s.

The katabatic flows at the Reno site were seen in both wind speed and temperature measurements. Figure 1 shows an example of the wind speed measured at the four tower levels in the morning hours of March 5, 2002. GMT is 8 hours later than local time, so this plot covers midnight through noon local time. The data is presented as 10-minute averages of the vector wind. One can see five pulses of increased wind speed, with peaks at approximately 10:00, 12:00, 13:30, 15:00, and 17:00 GMT. The increasing wind after 18:00 GMT is well after sunrise and not likely to be from katabatic flow. Students participating in this analysis are Mark McDaniel and Peter Hartsough. In general the gust speed is higher for the anemometers higher above the surface. Figure 2 shows periodic katabatic flow seen in the temperature (and relative humidity) measured on March 21, 2002. This plot also covers approximately midnight to noon local time. On this night, five pulses of cooler air are seen at approximately hourly intervals from 10 to 14 GMT.

In addition to tower measurements at this site, surface net radiation and downwelling radiation measurements may be useful in investigating the effects of katabatic flow. An interesting aspect of this study is speculation that the greatest cooling will occur just before morning. The beginnings of solar heating of the local slopes, or of the aerosol just above the slopes, could inhibit the next pulse of katabatic flow. This would allow the cold pool below (at the Reno site) a greater period of undisturbed radiational cooling.

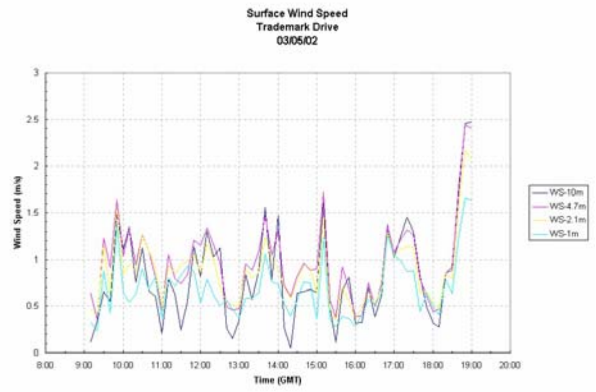

Figure 1: Four levels of wind speed in the early hours of March 5, 2002. Note the pulses at approximately two-hour intervals.

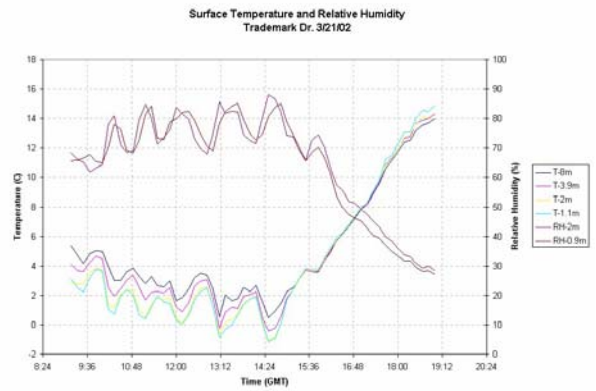

Figure 2: Four levels of temperature and two levels of relative humidity in the early hours of March 21, 2002. On this night, pulses of colder air are seen at approximately one-hour intervals.

3. A GUST FRONT AND DUST STORM

On February 28, 2002, near the beginning the ISS deployment, a severe dust storm triggered by a northerly cold and dry front brought a large amount of particulate matter (PM) into the Reno area. The synoptic and mesoscale evolution of this front is described in Section 5. Students participating in this analysis are Claudio Mazzoleni and Lynn R. Rinehart.

Atmospheric PM concentration is recognized as important because of its effects on human health, possible climate feedbacks, effects on vegetation, and on visibility. When inhaled, PM suspended in the air can be toxic or have mutagenic effects, depending on its chemical and physical characteristics. Climate and visibility effects are related to the particulate optical properties, and suspension time in the atmosphere is also a factor. Positive and negative climatic energy balance feedbacks are suspected and remain subject to study and controversial discussions. PM concentration also has application to considerable research devoted to the study of visibility, particularly in the vicinity of National Parks.

In the Reno basin, several stations of a pollution monitoring network collect hourly measurements of PM_{10} concentration (in $\mu g/m^3$). PM_{10} is the concentration of PM with diameter less than 10 μm. The hourly PM_{10} data during the February 28 event is being studied in the context of ISS surface measurements, and temperature and wind profiles, to document the time evolution of the dust event in Reno. Special attention is devoted to the time decay of the PM concentration after the maximum, which can be related to mixing processes and particulate sedimentation. Figure 3 shows the hourly PM_{10} concentration, which reached a maximum value of 474 $\mu g/m^3$ between 19 and 20 LT (compare this to the National Ambient Air Quality Standard maximum of 150 $\mu g/m^3$ for a 24-hour average). ISS wind and temperature profiles at both the Reno and Washoe sites show the gust front well correlated in time with the maximum PM_{10} measurement. For example, Figure 4 shows the northerly gust front in the Washoe basin (top) at 02:30 GMT and limited to below 1 km (red barbs), and a corresponding structure is seen slightly earlier in winds at the Reno site (bottom; orange barbs). 02:30 GMT corresponds to 18:30 LT.

The vertical structure of the gust front was also examined using radiosonde data available both before and after the frontal passage. The cooler and drier post-frontal air is clearly apparent.

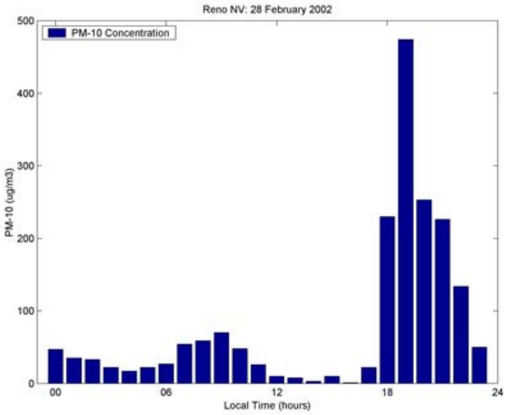

Figure 3: PM-10 concentration (ug/m3) on February 28, 2002. The extremely large values from 18-21 Z are dust carried through Reno by the strong gust front.

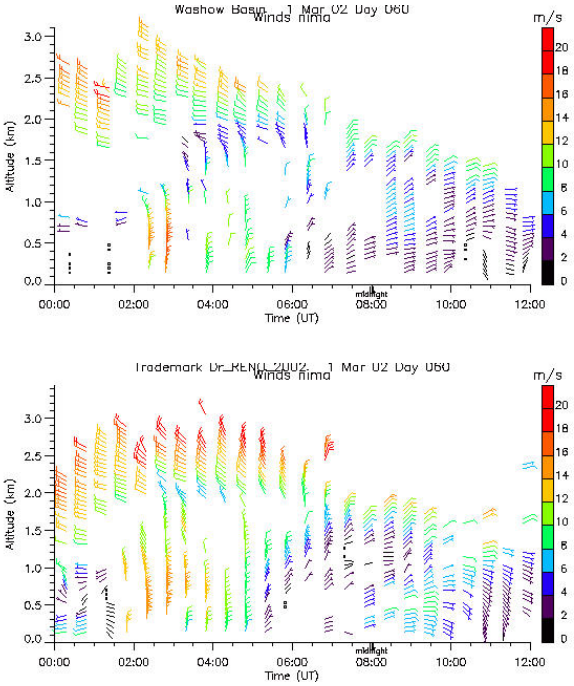

Figure 4: Wind profiler horizontal winds on March 1, 2002. Wind barbs are color coded by speed. Note the low level gust front after 2 UT; the Washoe ISS (top) shows the strongest winds slightly after the Reno ISS (bottom).

4. FRONTAL STRUCTURE AND EVOLUTION

Several cold fronts were observed by the ISS during the four week field operation period. One, which is being examined in detail by students Diana Ceballos and German Vidaurre, occurred in the early hours of March 14, 2002. Two fronts approached Nevada, from the north and from the west, influencing the surface pressure beginning on March 12. Winds became strong and primarily southerly from 12 GMT on March 12 through about 8 GMT on March 13. They then became northwesterly as the front approached over the Sierra Nevada Mountains, and finally became northeasterly. In addition to traditional synoptic analysis, the array of sensors in the Reno and Washoe basins allow the study of this event from two local perspectives. First, the evolution of the front aloft may be seen in both time and space as two wind profilers provide vertical cross sections a few tens of km apart; and second, the influence of basin topography can be studied as differences are seen at low altitudes between the two adjacent basins.

Figure 5 shows the complex evolution of winds aloft on March 14. The top frame shows a time-height cross section of radar signal strength, with the dark blue and red area generally corresponding to echoes from snow.

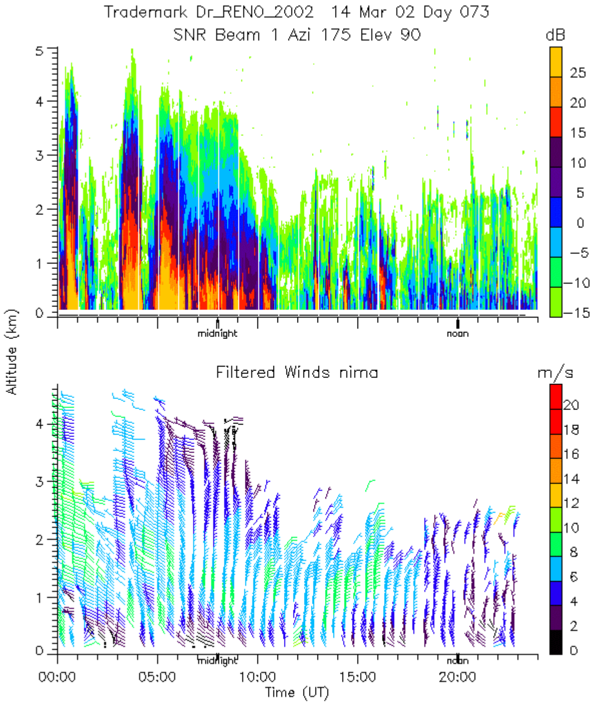

Figure 5: Wind profiler signal strength (top) and horizontal winds (bottom) on March 14, 2002.

The lower frame shows the winds with 30 minute resolution (and 60 m altitude resolution). Note that the wind barbs are color coded according to speed, so that green barbs are the highest momentum winds shown (8-12 m/s), blue barbs are more moderate winds (4-8 m/s), and black barbs represent light winds. Early in the day, before 07 GMT, all winds are from the northwest. Beginning at 07 GMT, winds aloft become northeasterly, and this shift descends, reaching the surface by 12 GMT. It is interesting that the strongest northwesterlies occur just below this transition line, forming a descending jet. Also, this transition line approximately represents the height of snow. While some snow is apparent above this line, the intensity increases by about 10 dB below it.

5. MESOSCALE DEVELOPMENT

During the first several days of the field experiment, a dramatic windstorm moved over the Sierra Nevada Mountains. The disturbance was tracked for three days from its origin over the mountainous region of southeastern Alaska. The disturbance followed a track from the northern extreme of the Rocky Mountains and then east of the Cascade Range and finally over the crest of the Sierra Nevada Range. The disturbance moved in an upper-level steering current that was directed along these mountain ranges and this disturbance was in evidence throughout the troposphere. The signature at the surface reporting stations was a sharp wind shift to northerly flow (with gusts to 40 knots) with abrupt drops in temperature and dew point temperature. The wind disturbance appeared to be split by the crest of the Sierra Nevada, with wind maxima west and east of the crest.

A short-lived dust storm (12-h duration) developed east of the crest, and moved through Reno, NV on the evening of February 28. The wind-generated mixing in the boundary layer over Reno was captured by the array of instruments deployed in the field experiment. The wind storm in the Sacramento and San Joaquin Valleys of central California was slightly delayed relative to the storm on the eastern slopes but was unequivocally associated with the same upper tropospheric disturbance.

Since the disturbance moved over the North American landmass where coverage by upper air stations in Alaska, Canada, and the Northwestern US was excellent, the upper-air analysis was able to accurately depict the structure of the disturbance. Yet, the operational numerical prediction models exhibited significant differences in the movement of the disturbance. This has led us to conduct research on the sensitivity of the low-level wind structure to the control elements in the prediction model. We are employing the MAMS (Mesoscale Adjoint Modeling System) that has been developed at NCAR over the past two decades. This model produced a forecast that was faithful to the wind event. The adjoint model has produced the sensitivity fields (derivatives of the model output with respect to the control variables in the forward model — the initial and boundary conditions). From these derivatives we can determine which meteorological variables have the most impact on the output (forecasted low-level wind in our case).

6. OTHER TOPICS OF STUDY

In addition to the topics described above, a number of other areas of investigation are being pursued using this data set. The evolution of a capping inversion was well captured on several occasions, showing the formation and breakup as well as multiple layers. Also, a set of rawinsonde launches was made, coordinated with NWS launches. The NWS site is several miles to the north and more than 100 m higher than the Trademark Drive site. Launches were timed so that they should be very well matched in altitude (the NWS launch was delayed as the ISS rawinsonde rose to the NWS launch altitude). This data will be examined for agreement between the measurements aloft, and to discern to what extent the ISS measurements capture low level features missed by the NWS.

6. CONCLUDING REMARKS

The Reno field program was designed to bring hands-on experience to graduate students having a sound knowledge of atmospheric science, but with little practical measurement experience. Such practical experience is necessary to assess the idiosyncrasies of different instruments, and to distinguish between spurious data from a poor or failed measurement and a truly unique observation where the physics are unusual but the observation can be interpreted in terms of real phenomena. The program followed a paradigm which includes identifying worthy goals and designing a plan of observation in support of these goals. As these students become skilled in their respective careers, exposure to the realities of measurement cannot be overemphasized, whether they end up in modeling, observation, or theory. We believe that this field program satisfied this paradigm and we are hopeful that the research outlined above will lead to advancement of our knowledge of atmospheric processes over the Sierra Range.

ACKNOWLEDGEMENTS

The resources and support of the NCAR/ATD and NSF made this project possible. Data collection and analysis benefited from contributions by Andy Goodrich and Linda O'Brien of the Washoe County District Health Department, John Bowen, John Gilles, and Greg McCurdy of DRI, Steve Cox of the NWS/Reno, and Lou Verstraete of NCAR/ATD. NCAR is operated by UCAR under sponsorship of the NSF.