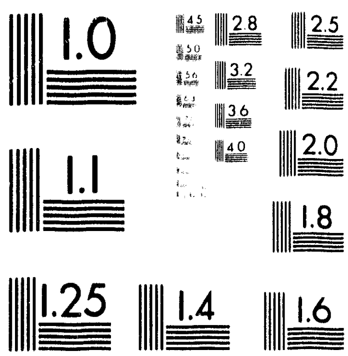

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MESOSCALE METEOROLOGICAL MEASUREMENTS CHARACTERIZING COMPLEX FLOWS

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ABSTRACT

Meteorological measurements are an integral and essential component of any emergency response system for addressing accidental releases from nuclear facilities. An important element of the U.S. Department of Energy's (DOE's) Atmospheric Studies in Complex Terrain (ASCOT) program is the refinement and use of state-of-the-art meteorological instrumentation. ASCOT is currently making use of ground-based remote wind sensing instruments such as doppler acoustic sounders (sodars). These instruments are capable of continuously and reliably measuring winds up to several hundred meters above the ground, unattended. Two sodars are currently measuring the winds, as part of ASCOT's Front Range Study, in the vicinity of DOE's Rocky Flats Plant (RFP) near Boulder, Colorado. A brief description of ASCOT's ongoing Front Range Study is given followed by a case study analysis that demonstrates the utility of the meteorological measurement equipment and the complexity of flow phenomena that are experienced near RFP. These complex flow phenomena can significantly influence the transport of the released material and consequently need to be identified for accurate assessments of the consequences of a release.

INTRODUCTION

Meteorological measurements are a key element of any emergency response system operating at a nuclear facility. Historically these systems have consisted primarily of surface observations and some tower observations. However, with currently available ground-based remote sensing equipment, profiles of winds and turbulence characteristics can be obtained routinely up to several hundred meters above ground level (AGL). These measurement capabilities can enhance considerably the ability of dispersion models to accurately predict the trajectories of released material, especially in areas with complex meteorology.

The U.S. Department of Energy's (DOE's) Atmospheric Studies in Complex Terrain (ASCOT) program is a basic research program studying the properties of the atmospheric boundary layer over nonuniform terrain.[1] One very important element of the ASCOT program is the refinement and use of meteorological measurement systems. ASCOT is currently making use of ground-based remote wind sensing instruments such as doppler acoustic sounders (sodars). These instruments are capable of continuously and reliably measuring winds up to several hundred meters above the ground, unattended.

A brief description of ASCOT's Front Range Study is given next, followed by discussion of phenomena observed in a case study analysis. This analysis demonstrates the utility of the measurement equipment and the complexity of flow phenomena that are experienced near DOE's Rocky Flats Plant (RFP). The phenomena identified and discussed are the behavior of a cold-air jet issuing from a canyon in the Front Range onto the plains near the RFP, and the layering of nighttime flows over the basin to the east of the RFP. These flow phenomena can significantly influence the transport of the released material and consequently need to be identified for accurate assessments of the consequences of a release.

ASCOT FRONT RANGE STUDY

A recent emphasis of the ASCOT program is to investigate and characterize the meteorology and dispersion potential of the atmosphere in the vicinity of the Colorado Front Range near DOE's RFP. Initial field studies included both an intensive period of observations in 1991 and continuous operation of a network of towers and sodars. Initial modeling studies included dynamic simulations and diagnostic analyses of the observational data. The ongoing study includes plans for additional measurements near one of the major canyons in the area and on a transect from the crest of the Rockies to the South Platte River.

The RFP facility is located at the interface between the Rocky Mountains and the Great Plains which provides some extremely complex flow patterns. The plant site is approximately 5 km east of the abrupt upthrust of the Front Range, on the eastern edge of an inclined bench (in this paper called the Rocky Flats bench) about 8 km wide (east-west) and 12 km long. Extensions of the bench form several ridges that bound shallow basins or valleys which are also inclined gently eastward toward the South Platte River. This topographic setting provides not only a geometrically complex lower boundary for the local atmosphere but ultimately much of the forcing for the nocturnal wind systems. The atmospheric scales of motion in the vicinity of the RFP site range from synoptic influences, through the influences of the large-scale topography to the west, to the small-scale processes of nocturnal surface cooling and drainage flows on the site itself and to the east.

Initial Front Range investigations were coordinated with a winter-time tracer experiment being conducted near the RFP for validation of the Rocky Flats emergency response modeling system.[1] These investigations include analysis of the meteorological and tracer data from an intensive experimental period (January-February 1991) and analysis of the meteorological data being collected continuously by the long-term network of meteorological equipment that has been operating since January 1991. Scientists in the ASCOT program are pursuing evidence pertinent to two operational hypotheses regarding local flow systems in the vicinity of the RFP:

- The major canyons in the area (Coal Creek and Eldorado) provide a significant fraction of the nocturnal cold air draining from the Front Range mountains to the west over the Rocky Flats area, and thus play a major role in determining the nocturnal transport and diffusion in this area.

- The structure of the cold air drainage evolves significantly with distance in the first 10 km from the mountains. This includes pronounced changes in the flow depth and speed.

A network of 2 mini-sodars and 9 towers has been operating continuously in the vicinity of the RFP since January 1991 as part of ASCOT's Front Range Study. The mini-sodars measure winds in 8-m layers centered on heights starting at 12 m and reaching maximum heights ranging between 50 m and 200 m. Most of the tower systems measure winds and temperatures at the 6-m and 18-m level and four measure net radiation. The network data are supplemented by routine tower measurements made at 10, 25, and 60 m on the RFP site. During a two-week period in January-February 1991 this network was part of a more extensive meteorological network consisting of 10 towers, 3 mini-sodars, 5 balloon-borne sensors, 2 radar profilers, and one lidar. Measurements from a subset of these instruments are analyzed and the results discussed in this paper.

BEHAVIOR OF COAL CREEK CANYON OUTFLOW

The experiment conducted on the night of February 4-5, 1991, has received considerable attention in the ASCOT community.[1,2] During this night, synoptic scale winds aloft were relatively weak northerlies and drainage flows off the eastern slopes of the Rockies became well developed. In other work,[2,3] the importance of the South Boulder Creek jet (outflow through Eldorado Canyon) on winds in the vicinity of the RFP has been described. The case study given here illustrates the importance of the Coal Creek canyon jet on winds in the vicinity of the RFP, by examining the observations from 4 towers, 2 mini-sodars, and balloon-borne sondes located at 5 sites (CC, PF, RF, BR, and FP) on or near a transect from the mouth of Coal Creek canyon into the Standley Lake basin just to the west of the RFP, as illustrated in Figure 1. One mini-sodar and one tower each were operated at CC and BR, towers were operated at PF and RF, and balloon-borne sondes were released from RF and FP.

The observations at CC (mouth of the Coal Creek canyon) reveal a well-defined steady jet of cold air issuing from the mouth of the canyon onto the plains to the east throughout the night. The mini-sodar observations indicate peak wind speeds in the jet at CC are about 7 m/s at roughly 50 m AGL, with the jet influence extending from the surface up through a depth of at least 120 m AGL[4]. The jet winds in the lowest 20 m, as measured by the tower at CC (Figure 2), are about 3 m/s from the west throughout the night at an average nighttime potential temperature of about 290.9K compared to an average nighttime potential temperature over the Rocky Flats bench at the same height AGL of about 292.9K.

This well-defined jet of cold air issues onto the Rocky Flats bench. The influences of this jet on the low-level winds in the vicinity of the RFP are investigated using the data presented in Figures 2 and 3.

Figure 2 shows the evolution of the winds with time at each of the tower locations. A very distinct shift in the measured wind speeds and directions occurs every 3-4 h at the two tower sites on the Rocky Flats bench (PF and RF). The average (in time and height) wind speeds change between 1.2 m/s and 3.0 m/s at both sites, and the directions change between west and northwest at PF, and between west and southwest at RF. The light westerly winds at both sites indicate the dominance of near-surface drainage flows in the vicinity of the RFP. The prevalence of the drainage flows is also supported by the observation that the speeds at the lower level on the PF and RF towers exceeded the speeds at the upper levels throughout the nighttime. These local drainage flows are interrupted at each of PF and RF at alternate times. That is, when the winds at PF are light from the west, winds at RF are stronger from the southwest (from the direction of the mouth of Coal Creek canyon), and when winds at RF are light from the west, winds at PF are stronger from the northwest (from the direction of the mouth of Coal Creek canyon).

These results strongly suggest that the Coal Creek canyon jet, after leaving the mouth of the canyon, oscillates between traveling in a southwestward direction (towards PF) and in a northwestward direction (toward RF). Further evidence that the Coal Creek canyon jet is alternately influencing PF and RF is that the potential temperature at the lowest level on the respective tower suddenly decreases by about 2.5K (to nearly the potential temperature of the Coal Creek canyon jet) when the jet is apparently influencing the site. The reason for the oscillation of e jet is not well understood; however, the timing of the direction switch of the jet is coincident with the dying out of the southerly winds above the bench after 2000, the establishment of northwesterly winds shortly after 2200 (the jet influencing PF), and the reestablishment of the southerly winds shortly after 0200 (the jet influencing RF).[2] Identifying the mechanism responsible for the oscillation of the Coal Creek canyon jet will require further investigations. The analysis given above shows that the Coal Creek canyon jet can significantly influence the near-surface winds in the vicinity of the RFP and consequently is an important phenomenon requiring attention in near-field dispersion estimates of near-surface releases at the RFP. The tower network and the mini-sodar observations in the mouth of Coal Creek canyon were instrumental in identifying the behavior of the jet in the vicinity of the RFP.

VERTICAL STRUCTURE OF WIND AND TEMPERATURE EAST OF THE RFP

The ground-level centerline of the tracer plume, from the continuous 10-m AGL release at the RFP, was observed nearly due east of the RFP on the 8-km sampling arc in a valley bottom.[2] The generally eastward transport of the plume appeared to result primarily from the local drainage flows originating on the flats and its gullies, as evidenced by the constant location of the ground-level plume center in spite of the highly variable larger scale flows.[2] Characteristics of the tracer plume, not yet known but potentially very important, are its vertical structure (Does it split apart?) and its location (Does it become elevated?). These questions are especially pertinent in light of the sudden drop of roughly 150 m in elevation from the Rocky Flats bench to the floors of the shallow valleys directly to the east. The previous discussion implies that the influence of the Coal Creek outflow could be significant in determining the vertical structure in the near field of the RFP site. Since vertical measurements of tracer were not made, the approach taken for qualitatively identifying the vertical structure and location of the tracer plume is the further analysis of available meteorological observations of winds and temperature, presented next.

The winds in the lowest 20 m AGL in the basin just to the east of the Rocky Flats bench (BR) are light and steady throughout the night at about 1.1 m/s at 240 degrees (Figure 2) at an average nighttime potential temperature of about 286.2K which is 4.7K colder than the Coal Creek canyon jet, and 6.7K colder than the near-surface air on the Rocky Flats bench. The BR tower level winds (lowest two levels at site BR in Figure 2) show no correlation with the pattern of the winds at the same height AGL at PF and RF, indicating no apparent influence of the Coal Creek canyon jet near the surface at BR. Rather, the BR tower winds appear to be strictly dominated by local drainage since their directions and speeds are steady throughout the night and aligned with the local topographic slope.

Above the surface drainage layer but below the elevation of the Rocky Flats bench the winds are especially variable in time and slightly variable in the vertical, as shown by the mini-sodar observations (Figure 2). Patterns do emerge, however, when the vectors are grouped into the same time windows as in the analysis of the Coal Creek canyon jet. The winds shown at hours 2200-0100 are very light, nearly stagnant westerlies, and the winds shown at hours 0300-0500 are stronger southwesterlies. Material introduced into these various flows would have different transport times and could shear slightly to moderately in the vertical, due to wind direction variations with height, depending on the actual height of the plume.

The northwest winds observed in the upper portion of the mini-sodar profile at the hour ending at 0200, are thought to be from the influence of the Eldorado canyon jet. This is supported by the lidar observations[3] and the free-release balloon sounding at FP where the Eldorado canyon jet passed over these locations during this time. Another point of interest is that the RF tower winds are very light during this time when the jet from Eldorado canyon could be influencing the RFP site. This implies that the strong northwesterly Eldorado canyon jet, observed in the Lidar measurements during the period between 0000 and 0200,[3] is elevated and decoupled from the surface at RF.

Another view of the vertical structure of the wind and temperature field above the BR site is given in Figure 3 where data from 4 towers, the BR sodar, a tethered balloon sounding at CC, and free-release balloon soundings at RF and FP have been superimposed in a vertical cross section. The potential temperature analysis indicates that tower level air passing both PF and RF is not cold enough to descend to tower level at BR or FP. This implies that the tower level air from the Rocky Flats bench (and thus the tracer) probably becomes detached from the surface and flows elevated out over the valley to the east of the RFP. This has significant implications on the potential exposure to ground-level concentrations. The immediate benefit of lower ground-level concentrations because the plume is farther from the ground, may be offset by the distant transport of an elevated plume through the night and the subsequent fumigation of the plume to the ground after sunrise. Another difficulty of treating an initial ground-level plume that becomes elevated is that it may move off in a different direction than a diagnostic model would show because the winds aloft are not well defined by the meteorological network or the model. Further investigation will be necessary to adequately characterize the influence of the CC jet east of the RFP and the layered flows there.

CONCLUSIONS

A network of towers and ground-based sodars was instrumental in identifying complex flow features in a very complicated terrain setting in the vicinity of the Rocky Flats Plant near Boulder, Colorado. One feature identified was the influence of a cold-air jet issuing from the Coal Creek canyon onto the Rocky Flats bench and sweeping across the bench at various times throughout the night, influencing the winds (and thus the tracer) at the RFP. The second important feature was the layering of nighttime flows over the valley to the east of the RFP. This implies that the ground-level tracer released from the RFP became elevated as it traveled to the east away from the RFP. These flow phenomena can significantly influence the transport of released material from the RFP and consequently need to be identified for accurate assessments of the consequences of a release. In general, meteorological measurements are a key element of any emergency response system operating at a nuclear facility.

ACKNOWLEDGEMENTS

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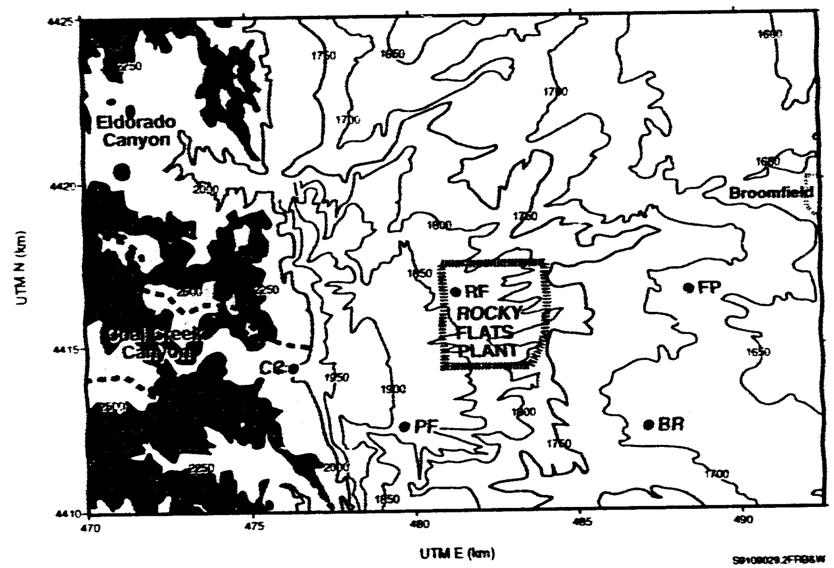
Figure Captions

1. Map showing terrain and meteorological measurement sites, discussed in this paper, surrounding the Rocky Flats Plant.

2. Time-height cross section of horizontal wind vectors measured on towers at sites CC, PF, RF, and BR, and from the mini-sodar at BR, for the night of Feb. 4-5, 1991. Vertical coordinate is height above ground level.

3. East-west cross section from CC at the mouth of Coal Creek canyon to BR at the floor of the valley to the east of the RFP for 2200 MST on Feb. 4, 1991. Balloon soundings at CC, RF and FP, and tower observations at CC, PF, RF, and BR, of winds and potential temperature are plotted. Winds from the mini-sodar at BR are also shown.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Coal Creek Canyon
CC
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ROCKY FLATS PLANT
PF
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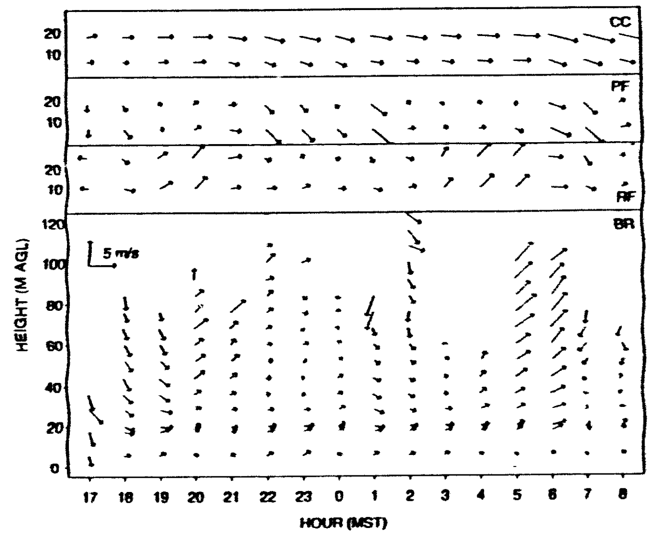
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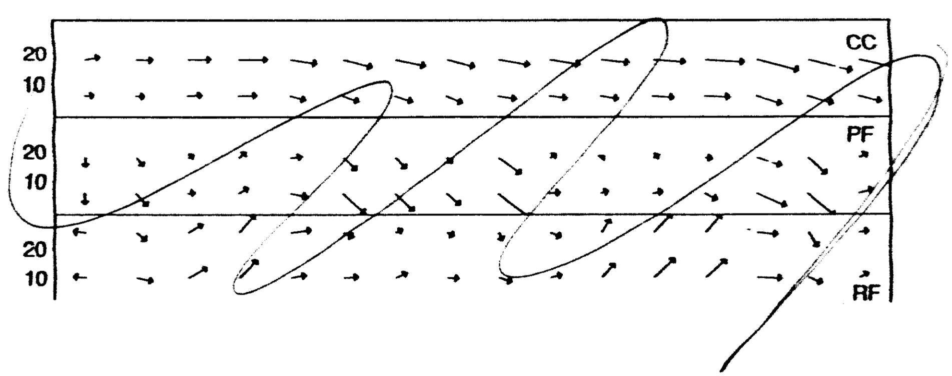
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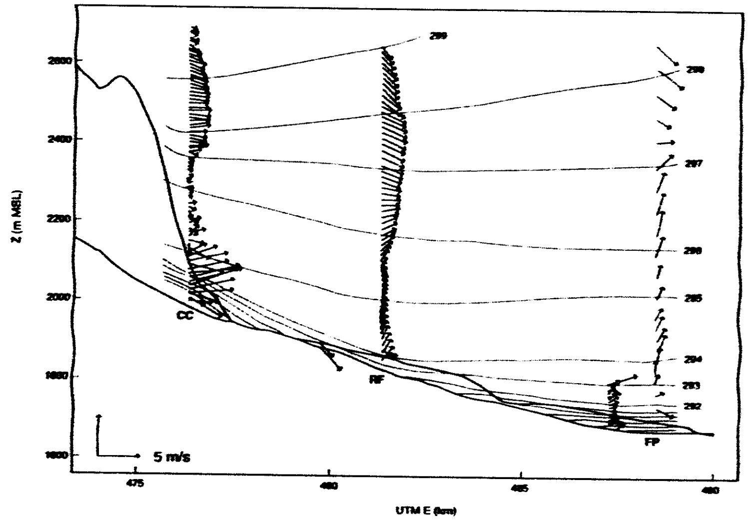
Balloon-sonde Potential Temperatures, February 4, 1991, 2200 MST



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