THE DEVELOPMENT AND CHARACTERISTICS OF A COLD AIR POOL IN A SMALL, ENCLOSED BASIN AND ITS RELATIONSHIP WITH REGIONAL AND LARGE-SCALE FORCING

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Abstract: Mean wind and turbulence data collected using an array of micrometeorological flux towers during the October 2006 METCRAX field campaign in Arizona's Meteor Crater were analyzed to investigate the relationship between regional-scale ambient flows and the characteristics of temperature inversions inside the crater. Five micrometeorological towers were located along an east-west cross section through the center of the crater. The analyses of 5-min mean data from all the towers showed that a strong temperature inversion formed inside the crater when ambient regional-scale flows were weak. Under these conditions, the temperature inversion was confined to the lowest 10-20 m above the basin floor, with the bulk of the basin atmosphere being nearly isothermal. Turbulence was intermittent within the temperature inversion, but was often nearly continuous in the isothermal layer above the shallow surface-based inversion. When the regional scale flows exceeded approximately 5 m/s, the basin atmosphere became fully coupled with the atmosphere above and little or no temperature inversion formed inside the crater. A regional-scale drainage flow from the southwest often formed on clear nights, producing winds of 2-7 m/s at the crater rim. Because these winds were near the threshold speed, the crater atmosphere exhibited a range of behaviours on individual nights.

Keywords: *temperature inversion, METCRAX 2006, basins, cold air pools*

1. INTRODUCTION

In October of 2006 the month long Meteor Crater Experiment, or METCRAX, collected continuously mean meteorological variables and turbulence fluxes using an array of micrometeorological flux towers and tethersonde soundings inside Arizona's Meteor Crater to investigate the formation of temperature inversions and seiches in a small, closed basin. Background atmospheric conditions were also determined using a radar wind profiler/RASS, a sodar/RASS, and frequent rawinsonde soundings in addition to numerous weather towers in the vicinity of the crater. (Whiteman et al., this volume). While several other studies have used the data set to investigate the development of slope flows on the crater sidewalls (Clements et al., this volume), the difference between the temperature inversion inside the crater and that over the plain (Hahnenberger et al., this volume), and the radiation balance in the crater (Hoch and Whiteman, this volume), this study focuses on the conditions that lead to the decoupling of the basin atmosphere with the ambient atmosphere over the plateau where the crater is cut into. Among the interesting findings from the observations is the existence of a regional scale downslope flow on the plateau (Zhong and Savage, this volume), which had significant impact on the ambient conditions for the crater especially when the synoptic scale forcing was weak.

2. DATA

The analyses here used the five micrometeorological towers in METCRAX that were located along an east-west cross section through the center of the crater (Fig. 1). Serving as the ground level, the 30 ft floor (flr) flux tower is located near the center of the crater. The two 'lower' towers, which are also 30 ft tall, are located both on the east slope (el) and west slope (wl) approximately 6 m above the crater's floor and serve as an intermediate location. Finally the 20 ft 'upper' towers are arranged on the east (eu) and west (wu) sidewalls approximately 20 m above the crater floor. Mean and turbulence measurements were made continuously by instruments at multiple levels through the month-long experiment to document the conditions inside the crater. The background atmospheric conditions were determined by a 10 m tripod on the highest point on the crater rim on the northwest side of the crater.

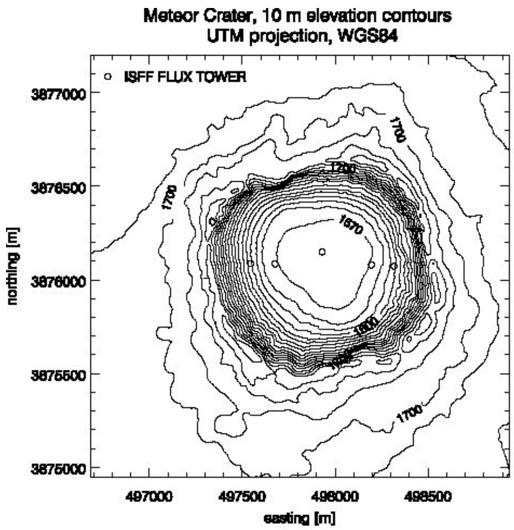

Figure 1. The topography of the Meteor Crater and the locations of the flux towers

3. PRELIMINARY RESULTS

The five-minute mean data of the month-long observations from the tower array indicate that the basin atmosphere is characterized by three regimes. The first is the development of a strong temperature inversion towards the base of the crater, or the lowest 10 m above the floor, with a near isothermal atmosphere above the inversion. The structure and evolution of the temperature inversion is illustrated in Figure 2 on the night of 22 October or IOP5. The inversion began to form shortly after sunset. The strength of the inversion increased rapidly in the evening hours, reaching almost 7-8 ^{o}C in the lowest 5-10 m between the floor and the two lower sidewall towers, and another 1-2 ^{o}C from the lower to the upper sidewall towers that were separated by about 20 m in height above the crater floor. During the rest of the night, the strength of the inversion and the vertical structure remained more or less unchanged. Also shown in Figure 2 is the vertical velocity variance, which indicates that turbulence was intermittent within the temperature inversion except for the upper west slope site (wu) where turbulence was nearly continuous even at night. This turbulence was found to be mechanically generated by wind shears as a result of the intrusion of a moderate southwesterly flow that frequently developed along the gentle slope from the Little Colorado River Valley upward towards the southwest (Zhong and Savage, this volume). A completely decoupled case, such as discussed above, was seen on eight nights in the 31 day field campaign. Accompanying these inversion cases were weak synoptic and regional scale flow throughout the night. Table 1 shows all eight occurrences of decoupled flow inside the crater, with the background wind represented by the RIM measurements on each day, which were all at or below 5 m s^{-1}.

Observed days with ambient flow greater than 5 m s^{-1} created a different microclimate within the crater. The mean background winds on these days are given in Table 2, and are classified as coupled cases because the basin atmosphere became fully coupled with the atmosphere above and little or no temperature inversion formed inside the crater. Similar to Figure 2, Figure 3 is a temperature time series taken from the five flux towers on the night of Oct. 5. The regional ambient flow surrounding the crater on this night was 8.0 m s^{-1}, well above the 5.0 m s^{-1} mentioned earlier as a potential threshold. The effect of this strong synoptic and regional forcing can easily be seen by the non-existent temperature inversion in Figure 3. Inversion development is most likely hindered by the fairly continuous turbulence indicated by the vertical velocity variance of 0.5 m^{2} s^{-2} throughout the night, preventing cold pool development in the base of the crater. With this turbulent mixing, temperatures at all towers within the crater seem to ‘plateau’ throughout the night.

Table 1. Background wind on decoupled days

Date	Direction	Wind Speed
Oct. 7	SSW	4.0 m/s
Oct. 19	SW	4.0 m/s
Oct. 21	W	3.5 m/s
Oct. 22	W	3.0 m/s
Oct. 27	W	4.0 m/s
Oct. 1	SW	5.0 m/s
Oct. 18	W	3.0 m/s
Oct. 26	W	4.0 m/s
	AVG:	3.8 m/s

Table 2. Background wind on coupled days

Date	Direction	Wind Speed
Oct. 5	SE	8.0 m/s
Oct. 30	SW	6.0 m/s
Oct. 3	S	6.0 m/s
Oct. 4	SW	6.0 m/s
Oct. 6	SSE	7.0 m/s
Oct. 9	S	5.0 m/s
Oct. 15	SW	7.0 m/s
	AVG:	6.5 m/s

A third pattern that developed inside the crater was a combination of both a coupled and decoupled atmosphere. Several nights throughout the month the ambient flow around the crater would transition from strong winds above 5 m s^{-1}, coupling the crater with the atmosphere above, to a more quiescent flow, allowing an inversion to develop. Partially decoupled nights were also seen in reverse, where a decoupled microclimate would give way to stronger winds aloft that developed over night. On Julian day 296 in Figure 2, an example of increased synoptic or regional forcing can be seen affecting the temperature inversion. Turbulence slightly increases to near 0.5 m^2 s^{-2} at this time, which raises the floor temperature by almost 3 ^{o}C shortening the gap between the three layers. This example is brief, but provides a sample of other typical partially decoupled nights that saw a sudden increase in ambient forcing.

4. SUMMARY

METCRAX provided a unique opportunity to examine the microclimate of the Arizona Meteor Crater throughout the month of October 2006. Analysis shows three separate classifications on how the regional and synoptic scale flow interacted with atmosphere in the small, enclosed basin. A threshold wind speed of 5 m s^{-1} was the determining factor for inversion development inside the crater. Nights with regional ambient flow below this threshold would often see inversion development in the lowest 10 to 20 m of the basin with a strength of 5 to 10 ^{o}C. If the regional flow was above 5 m s^{-1} turbulence increased substantially over the basin, destroying any developing temperature inversion and coupling the crater with the atmosphere above. A regional-scale drainage flow from the southwest often formed on clear nights, producing winds of 2-7 m s^{-1} on the westside of the crater rim. Because these winds were near the threshold speed, the basin atmosphere would often become partially decoupled, creating inversions and then destroying them as winds increased. Further detailed investigations are needed to document the basin atmosphere and its relationship with ambient atmospheric conditions as determined by synoptic scale and regional scale forcing.

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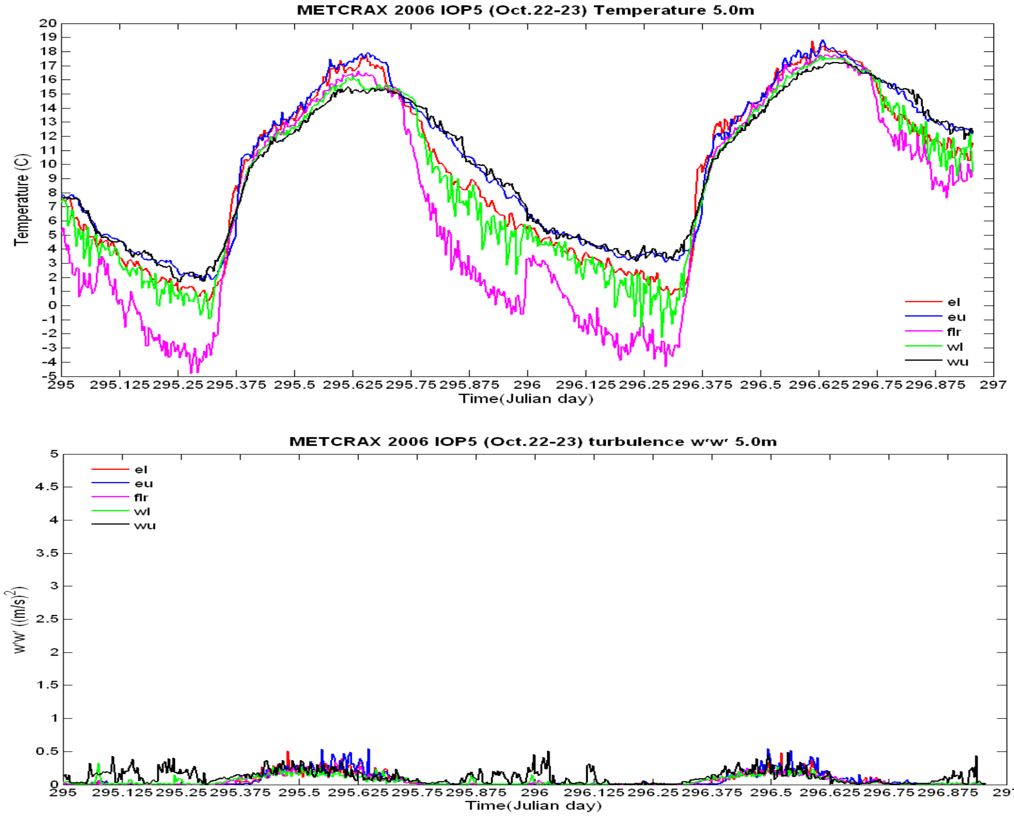

Figure 2: Temperature profile and velocity variance for 22-23 Oct. at each tower location.

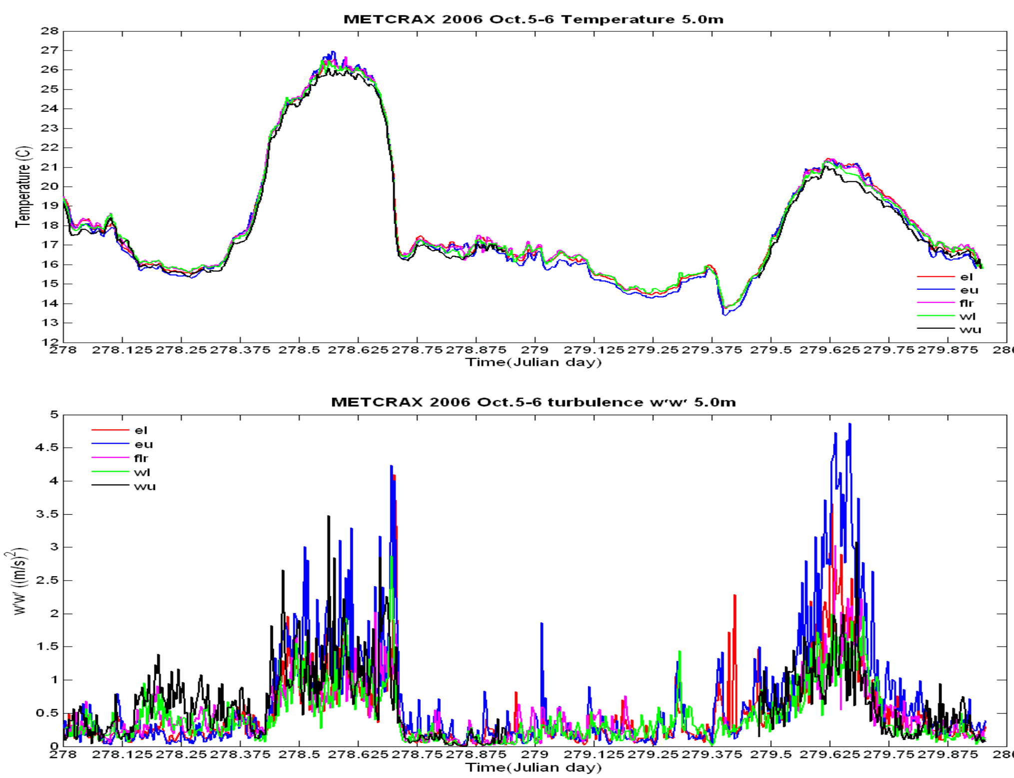

Figure 3: Temperature profile and velocity variance for 5-6 Oct. at each tower location.