10.4 THE EFFECTS OF UNCERTAINTIES IN BOUNDARY LAYER HEIGHTS ON URBAN DISPERSION DURING THE DAYTIME IN OKLAHOMA CITY

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1. INTRODUCTION

The Joint Urban 2003 (JU2003) meteorological and dispersion study (Allwine, et.al, 2004) was conducted in Oklahoma City (OKC) in July 2003 to acquire data for use in evaluating current urban wind field and dispersion models and developing new or improved models. JU2003 included six daytime and four nighttime Intensive Observation Periods (IOPs) during which the tracer sulfur hexafluoride (SF_6) was released for 30-min periods. There were three such releases, separated by two hours, during each IOP studied here. The SF_6 from these releases was sampled by bag samplers at outer arc distances of 1, 2, and 4 km from the release location. There were many other samplers operating in the central business district, at distances less than 1 km, but they are not studied here.

Analyses of the tracer concentration measurements, normalized to account for differences in tracer dissemination, show that the tracer concentrations measured during IOP 5 were substantially higher than the concentrations measured under apparently similar meteorological conditions during the other daytime IOPs. The bar chart in Figure 1 displays these anomalous high normalized concentrations. Each time period has three groupings of vertical bars, which indicate the arc maximum normalized concentrations at the three arc distances of 1, 2, and 4 km. The arc maximum normalized concentrations for IOPs 3, 4, 5, and 6 are denoted by the black, red, green, and yellow colored bars, respectively. The start times for the 30-min SF_6 releases during IOPs 3 and 4 were 1600, 1800, and 2000 UTC, while the start times for the SF_6 releases during IOPs 5 and 6 were 1400, 1600, and 1800 UTC.

Figure 1 shows that the arc maximum normalized concentrations measured during the first two SF_6 releases of IOP 5 (1400 and 1600 UTC) were almost an order of magnitude higher than those measured at the same times of day during the first two releases of IOP 6 and the first release of IOPs 3 and 4. The arc maximum normalized concentration measured during the third release of IOP 5 was comparable to the levels measured during the other IOPs for the same time period.

We used the Defense Threat Reduction Agency's (DTRA's) Hazard Prediction and Assessment Capability (HPAC) 4.04 modeling system (DTRA, 2004), which contains the Second-order Closure Integrated Puff (SCIPUFF) and Urban Dispersion Model (UDM) atmospheric dispersion models, to calculate the arc maximum normalized concentrations for comparison with the concentrations measured at the arc distances of 1, 2, and 4 km. The same HPAC urban dispersion model option and meteorological inputs, including winds from an upwind site, were used in the HPAC predictions for all IOPs.

Figure 2 compares the predicted and observed maximum normalized concentrations for each of the three tracer releases for IOPs 3, 4, 5, and 6. The concentrations shown in this graph are arc maximum concentrations. That is, the maximum predicted and observed concentrations at each sampling arc do not necessarily occur at the same sampling location on the arc. The solid diagonal line represents perfect agreement and the dashed lines represents factor of 2 differences between predicted and observed normalized concentrations. The general tendency is for HPAC to underpredict the observed normalized concentrations, with most of the values for IOPs 3, 4, and 6 near the lower factor of 2 line. However, the HPAC predictions for the first two releases of IOP 5 are nearly an order of magnitude lower than the observations. The correspondence between predicted and observed concentrations for the third release of IOP 5 is comparable to that obtained for the other IOPs.

2. STUDY OBJECTIVE AND HYPOTHESIS

The objectives of our study were to determine the cause of high anomalously normalized concentrations measured during the first two releases of IOP05 and to understand the reason for the differences in HPAC model performance between IOP05 and the other daytime IOPs. Possible explanations for the higher normalized concentrations measured during the first two releases of IOP 5 include differences in wind-speed profiles and differences in boundary layer heights. Higher wind speeds increase the dilu-

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tion of the tracer plume, reducing the concentration. Lower boundary layers (mixing layers) yield higher concentrations by inhibiting upward dispersion.

A previous study by Hanna, et.al. (2007) found the maximum IOP-average wind speed difference between daytime IOPs was relatively small, 1.2 m/s, suggesting that variations in wind speed alone could not explain the order of magnitude differences in observed normalized concentrations. Consequently, our hypothesis was that the higher observed normalized concentrations were related to differences in the heights of the boundary layer. We also hypothesized that the boundary layer heights that HPAC computes when run in the default mode were too high for the first two releases of IOP 5.

3. DATA SOURCES AND RESULTS

We examined temperature and humidity profiles from the Argonne National Laboratory (ANL) and Pacific Northwest National Laboratory (PNNL) radiosonde releases to determine the boundary layer depths during each of the IOPs of interest. Additionally, we examined boundary layer heights estimated from the boundary layer turbulence measured by Dugway Proving Ground's Frequency Modulated/ Continuous Wave (FM/CW) radar (Gallagher, et.al., 2004). The ANL radiosonde site was approximately 4.3 km north of the OKC Botanical Gardens release site, the PNNL radiosonde site was approximately 2.2 km southwest of the release site, and the FM/CW radar was approximately 1.5 km north of the release site. Each of the radiosonde launches occurred at or near the start of each of the continuous releases. The FM/CW radar provided continuous readings of the boundary layer turbulence structure from which boundary layer heights were inferred.

Tables 1 and 2 list the boundary layer heights estimated for IOPs 5 and 6, respectively. The FM/CW boundary layer heights were estimated from the radar measurements at the start times of the tracer releases. As shown by the fourth column in each table, the average observed boundary layer height ranged from approximately 100 to 490 m for IOP 5 and from approximately 400 to 1200 m for IOP 6. Thus, the observed mean boundary layer heights for IOP 6 were 3 to 4 times higher than the mean boundary layer heights for IOP 5.

Figure 3 shows time series plots of estimated FM/CW radar boundary layer heights for the four daytime IOPs. The black trace represents the IOP03 boundary layer height, the green trace represents IOP04, the red trace represents IOP05, and the blue trace represents IOP06. The red horizontal lines at the top of the figure identify the SF_6 release periods. As shown in the figure, the boundary layer heights for IOP 5 are considerably lower than the heights for the other IOP periods.

Table 1. Boundary layer heights estimated for IOP 5 from ANL and PNNL radiosonde soundings and FM/CW radar turbulence profiles.

Release Time (UTC)	Boundary Layer Height (m)			
	ANL	PNNL	FM/CW	Avg.
1400	102	99	97	99.3
1600	181	209	166	185.3
1800	531	429	508	489.3

Table 2. Boundary layer heights estimated for IOP 6 from ANL and PNNL radiosonde soundings and FM/CW radar turbulence profiles.

Release Time (UTC)	Boundary Layer Height (m)			
	ANL	PNNL	FM/CW	Avg.
1400	No Data	454	418	436.0
1600	869	735	650	751.3
1800	1209	1294	1099	1200.7

4. SYNOPTIC EVALUATION

We examined the synoptic situation on 13 July 2003 in search of an explanation for the anomalously low boundary layer heights for IOP 5. National Weather Service observations at the Wiley Post Airfield reported mostly cloudy to cloudy conditions over the OKC area from 0700 to 1400 UTC on 13 July 2003, but no precipitation. However, one of the surface observations from the Norman, OK weather station, located to the south of OKC, reported lightning to the distant NW during this time period, indicating that there was some convective activity in the area. Figure 4, the weather surface map analysis for 0000 UTC 13 July 2003, shows a propagating wave moving along a stationary front. The frontal boundary is over OKC, which is shown by the red star. As shown in figure 5, the wave had moved into northwest Arkansas by 1200 UTC 13 July.

Figure 6, a radar map analysis at 1045 UTC 13 July 2003, shows a general area of convective activity from southwest to north of OKC. This analysis is consistent with the observation of lightning reported by the Norman, OK weather station at this time. As time progresses, the area of convection appears to dissipate in energy and coverage (see Figure 7), However, the line of cells along the Oklahoma – Arkansas border in Figure 6 intensifies with time and develops into a mesoscale convective complex by 1345 UTC, as shown in Figure 7. The timing of this development corresponds to the location of the propagating wave along the frontal boundary at 1200 UTC 13 July (Figure 6).

Our assessment is that the combination of the outflow from the nearby convective activity along with the propagating wave along the frontal boundary may have forced the boundary layer heights on the morning of IOP 5 to shallow heights more representative of night-time situations.

5. HPAC MODELING PERFORMANCE ASSESSMENT

We next compared the boundary layer heights derived from the PNNL radiosonde soundings with the boundary layer heights computed by HPAC run in its default mode for each release time of IOPS 3, 4, 5, and 6. As shown by Figure 8, the HPAC boundary layer height predictions for IOP 5 are more than a factor of 2 larger than the observed heights. In contrast, all of the boundary layer heights predicted by HPAC for the other IOPs are within a factor of 2 of the observed values.

As a final step, we repeated the HPAC model calculations for IOPs 3 through 6 using the same meteorological data and urban modeling options as in the previous runs, but with the boundary layer heights estimated from the PNNL radiosonde soundings. As shown by Figure 9, use of the observed boundary layer heights improves the correspondence between predicted and observed arc maximum normalized concentrations, especially for IOPs 5 and 6.

5. CONCLUSIONS

This study suggests that the high normalized concentrations measured during the early releases of IOP 5 can be attributed to unusually low boundary layer heights, which are evident in the radiosonde and FM/CW radar measurements. This study also illustrates that standard operational use of a dispersion model may not account for atypical weather situations unless meteorological measurements or analyses that capture those conditions are used in the place of the model default parameters.

Finally, atmospheric dispersion field studies almost always are conducted under fair-weather conditions, both because of safety concerns and because of the desire for well-behaved dispersion patterns. However, as illustrated by the tracer concentration measurements made during JU2003 IOP 5, critical meteorological regimes, resulting in the highest concentrations, can be missed when dispersion studies are restricted to fair weather.

6. REFERENCES

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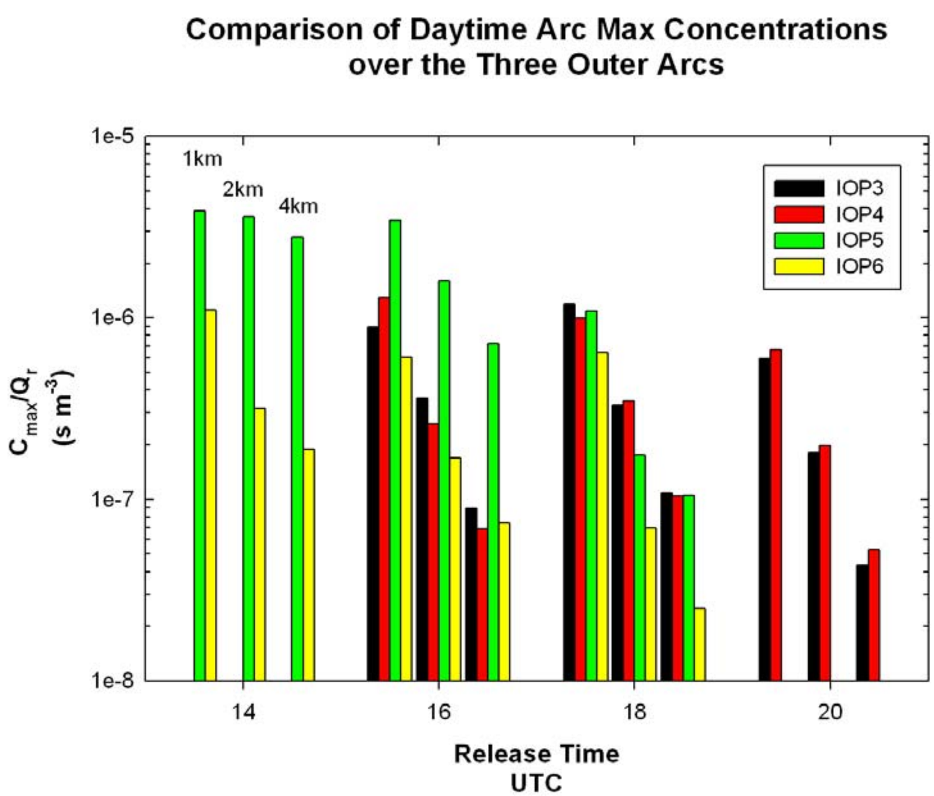

Figure 1. Comparison of arc maximum concentrations over the three outer sampling arcs.

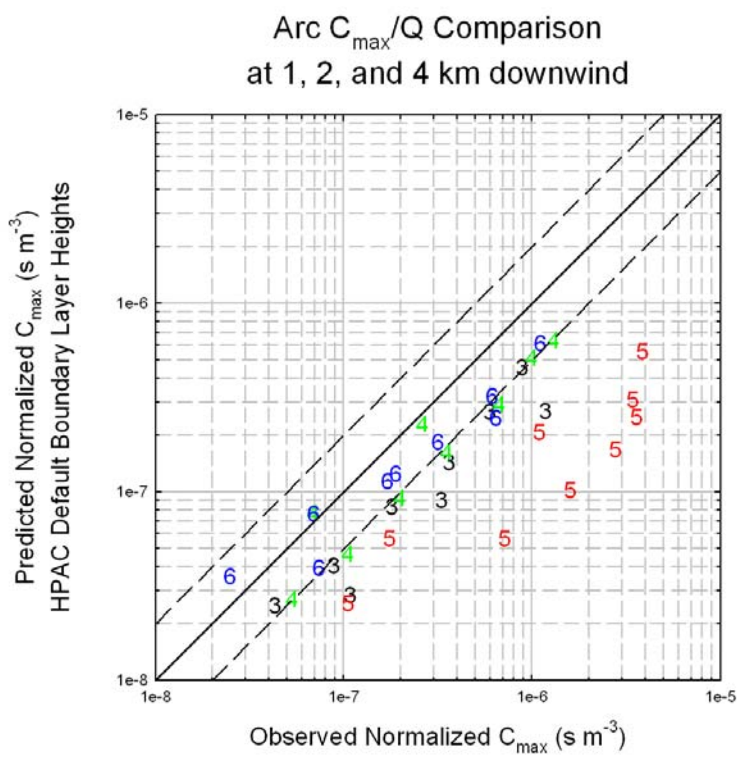

Figure 2. Comparison of arc maximum observed and HPAC-predicted normalized concentrations for IOPs 3, 4, 5, and 6.

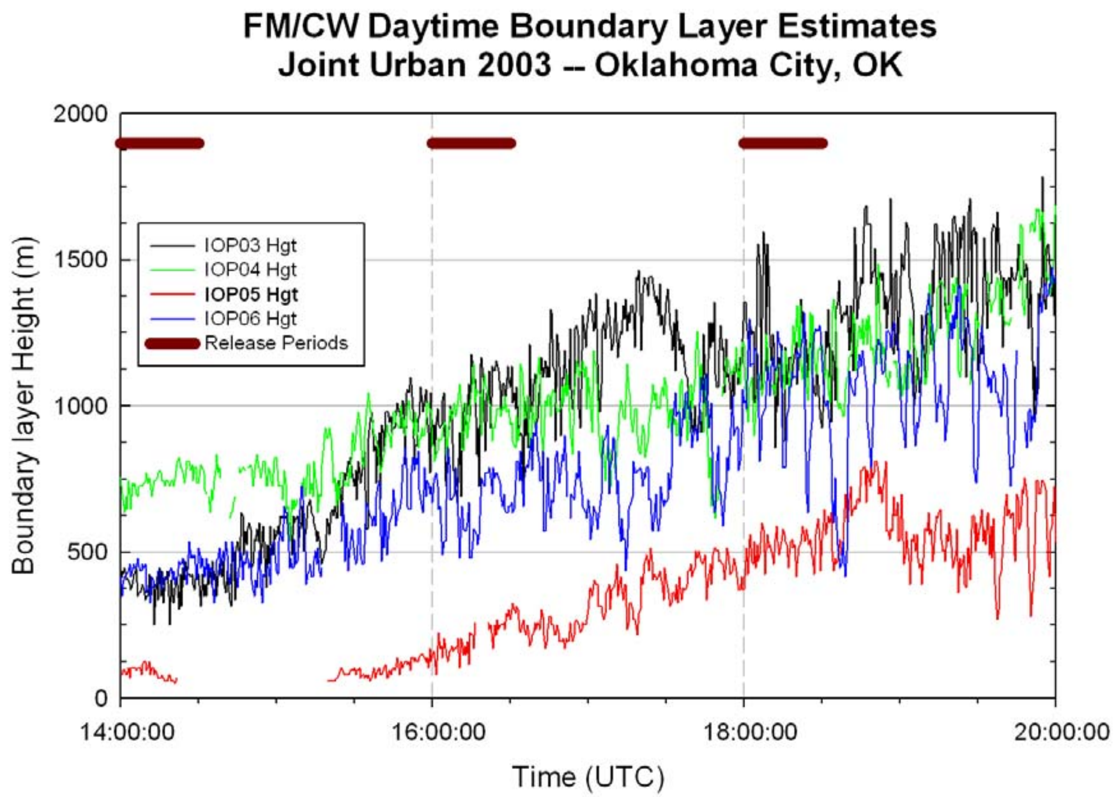

Figure 3. FM/CW radar boundary layer height estimates for the daytime IOPs.

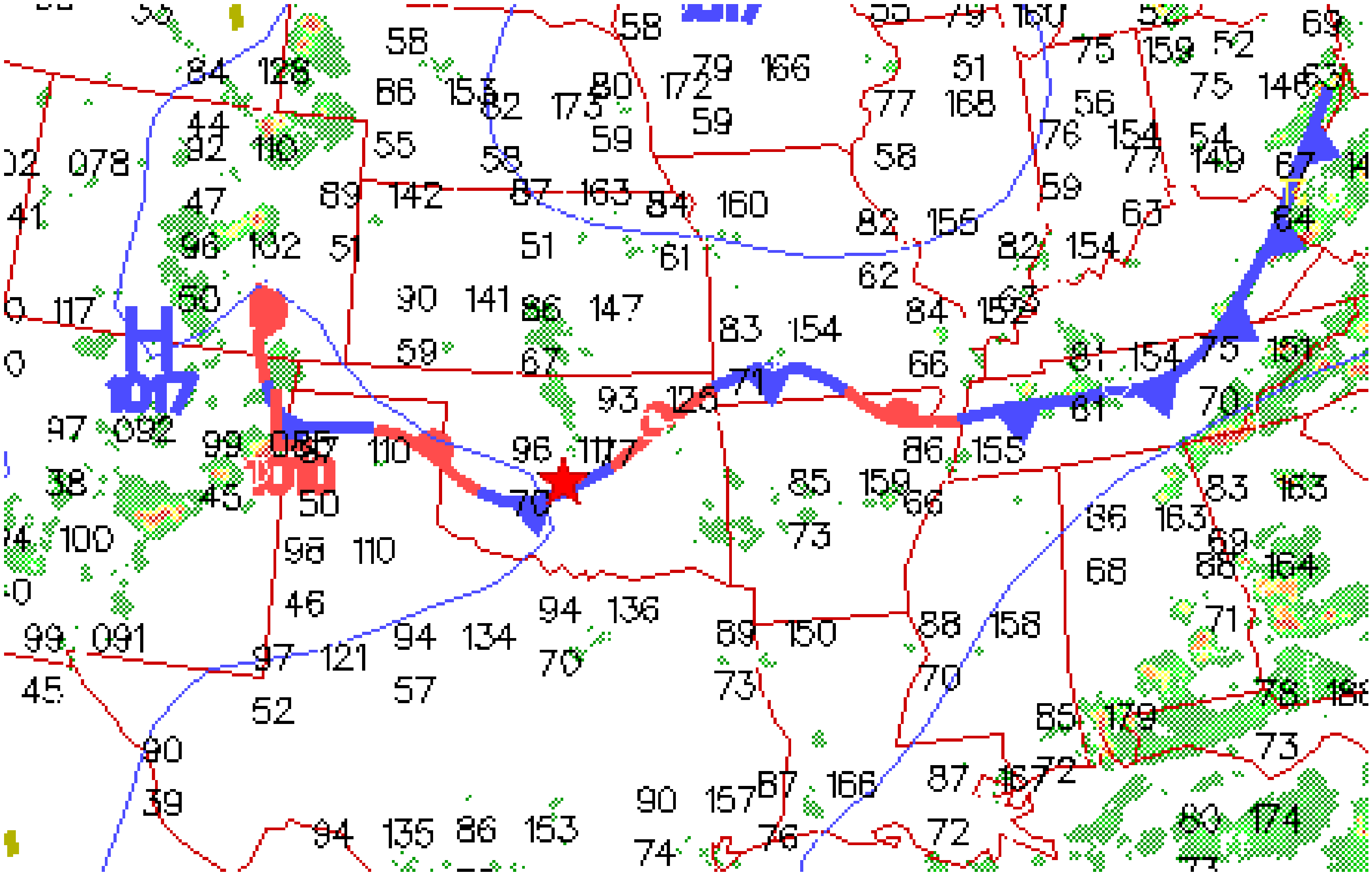

Figure 4. Surface weather map analysis for 0000 UTC 13 July 2003. The red star shows the location of OKC.

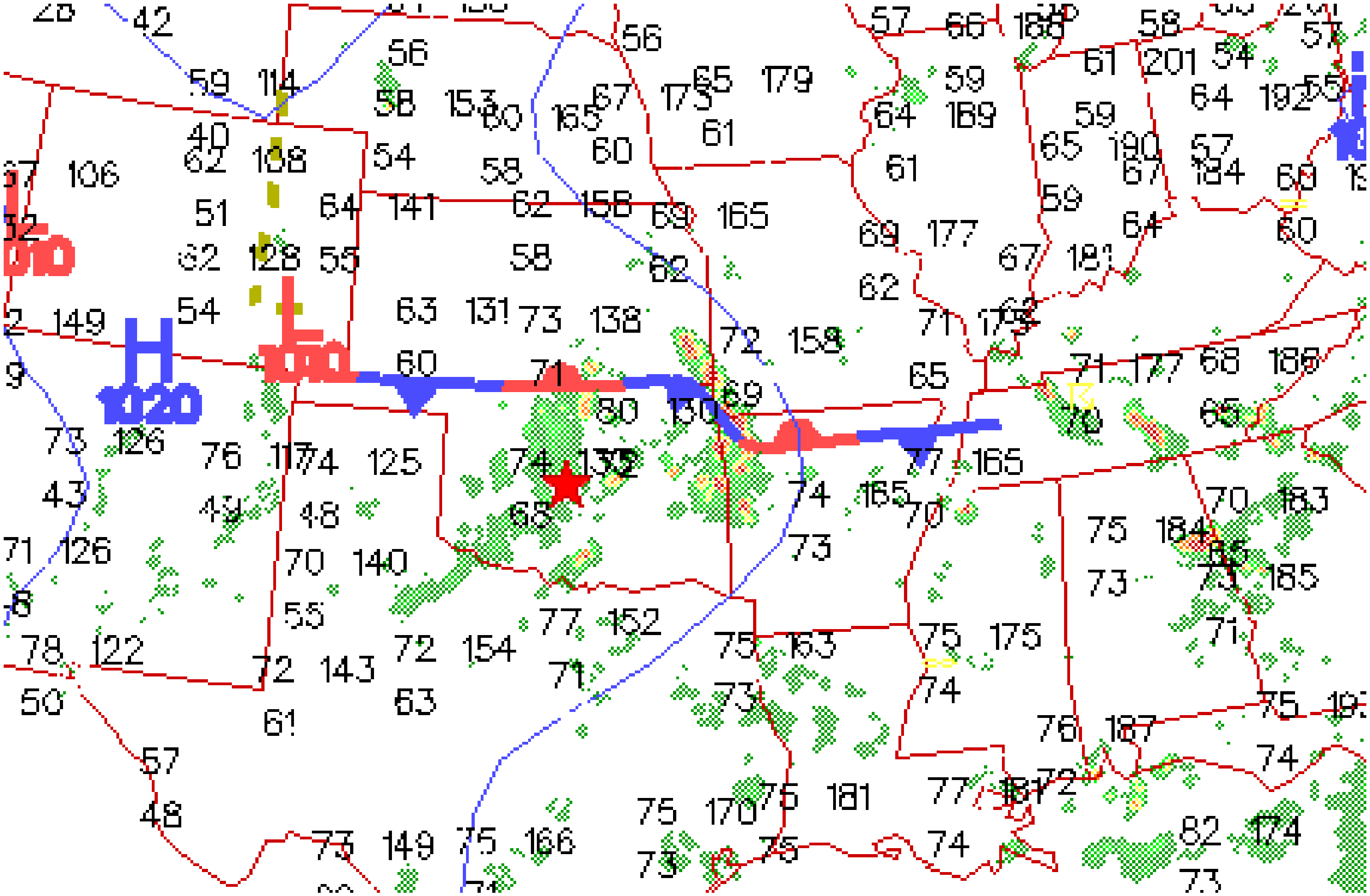

Figure 5. Surface weather map analysis for 1200 UTC 13 July 2003. The red star shows the location of OKC.

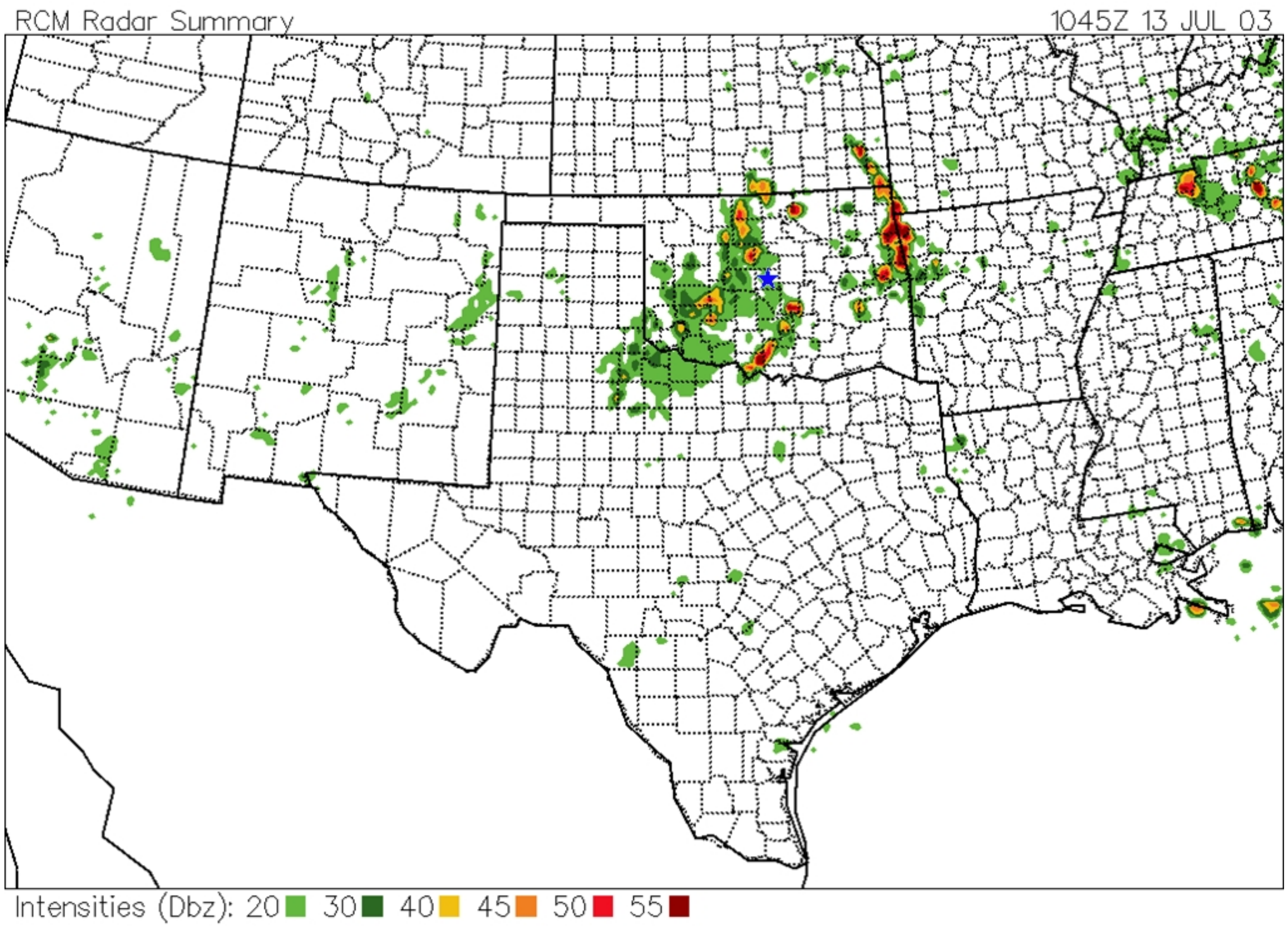

Figure 6. Radar map analysis at 1045 UTC 13 July 2003. The blue star shows the location of OKC.

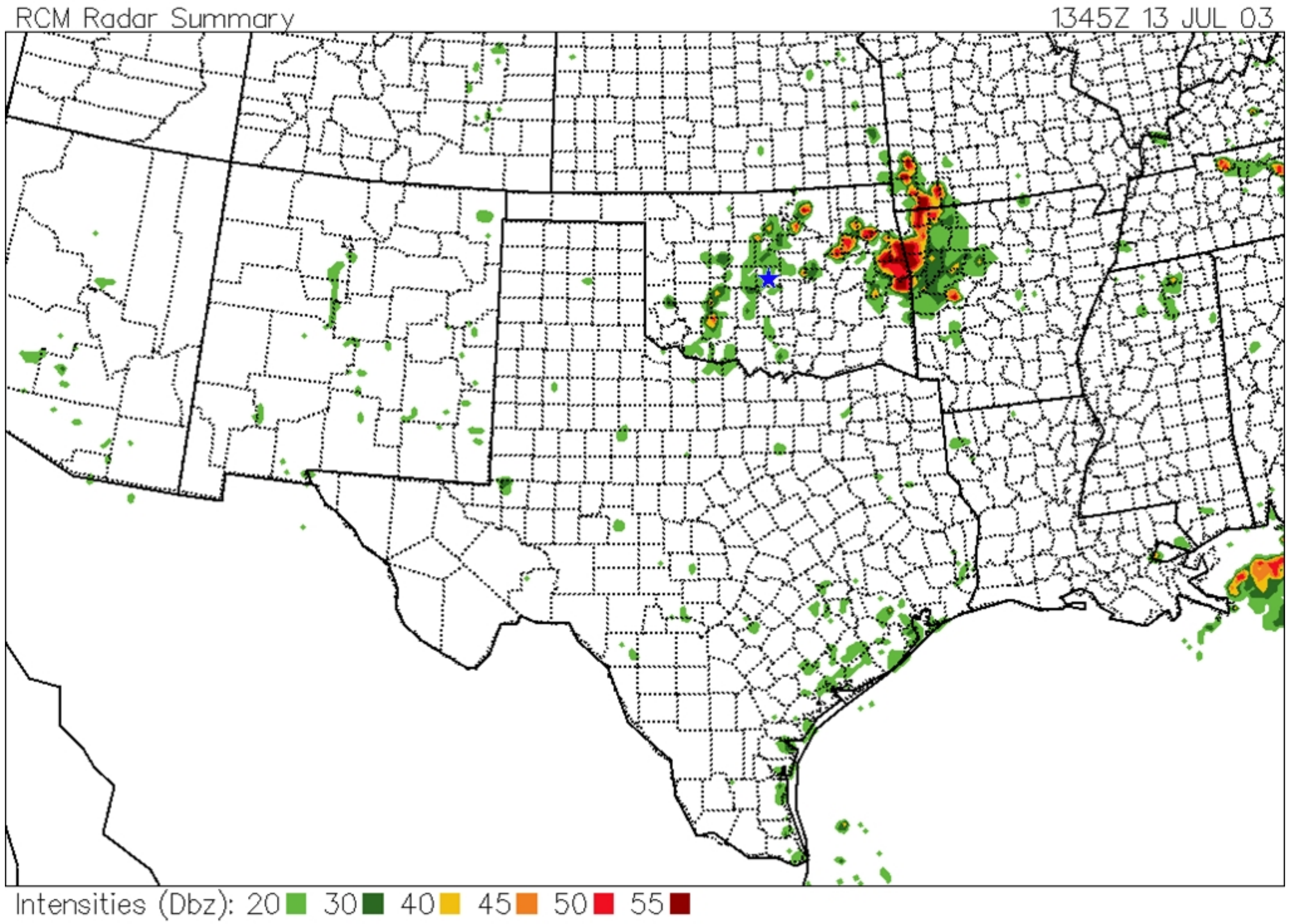

Figure 7. Radar map analysis at 1345 UTC 13 July 2003. The blue star shows the location of OKC.

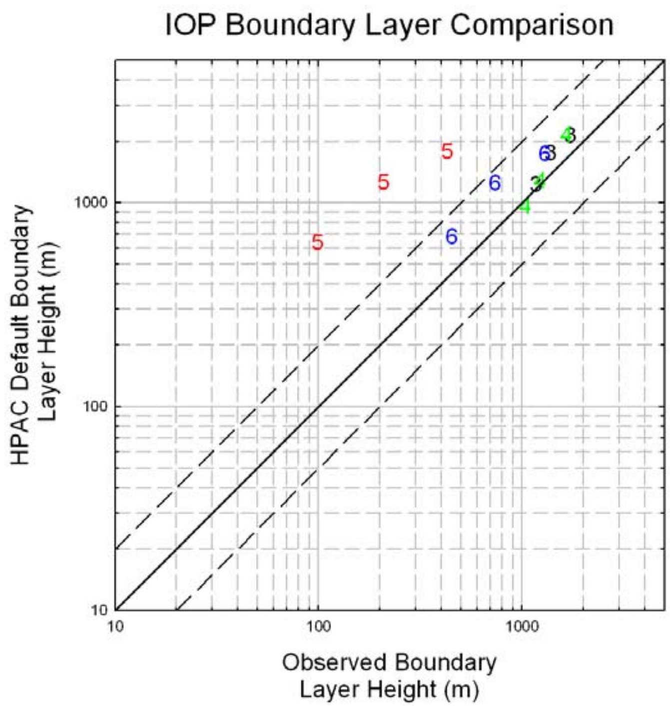

Figure 8**.** Comparison of observed boundary layer heights with HPAC default boundary layer heights

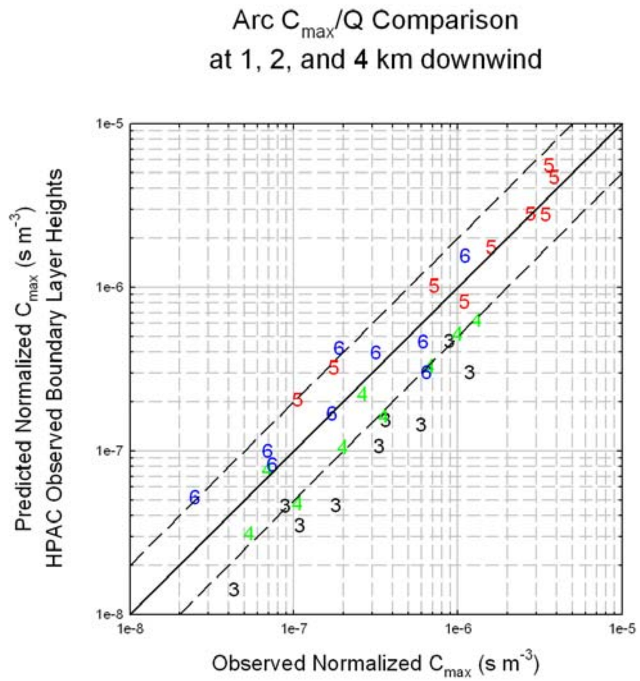

Figure 9. Comparison of arc maximum observed and HPAC-predicted normalized concentrations for IOPs 3, 4, 5, and 6. This figure differs from Figure 2 in that observed rather than computed boundary layer heights were used in the HPAC predictions.