P1.13 ARE THERE MESOSCALE, CONVECTIVE “WEATHER HOLES”?

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1. INTRODUCTION AND BACKGROUND

Most meteorologists are acquainted with the notion of a “weather hole,” that is, a location that storms often barely miss or near which approaching storms often dissipate. Put more plainly, a weather hole is a location that receives less interesting weather than the surrounding area. In our experience, many meteorologists and interested civilians think that they live in weather holes. We have generally believed that such people simply enjoy experiencing interesting weather, are memorably disappointed whenever it misses them, and eventually conclude that their location is subject to some kind of meteorological disfavor. The recent availability of multiple years’ worth of national radar composites makes it feasible to address objectively whether the concept of a weather hole is reasonable, and to evaluate the degree to which selected sites may be weather holes (or even weather “hot spots”).

Preliminary work using 18 “target” sites (with large meteorological communities, such as at universities and research laboratories) shows that there are mesoscale patterns of spatial variability in a 5–year radar dataset. The frequency of echoes $\geq$ 20 dBZ is not significantly higher or lower at any of the 18 points than in their surroundings. However, it appears that there may indeed be local holes and hot spots when echoes $\geq$ 40 dBZ (i.e., convective precipitation) are considered, much as many weather enthusiasts suspect. Even so, sites that meet multiple subjective criteria for being a weather hole are rare in our investigation.

2. MOTIVATION

Although friendly hallway debates about weather holes perhaps do not constitute a pressing scientific problem, the present preliminary results represent an effort to satisfy our curiosity while simultaneously accomplishing the broader goal of demonstrating a method for constructing worthwhile local climatologies of convective echoes using a comparatively new radar dataset. Such local climatologies may improve both the public’s risk awareness and the nowcasting of strong thunderstorms in various regions. For example, building upon these results, it may be possible to compute mean regional probabilities that ongoing, upstream convective storms will strike populated areas, thereby providing helpful statistical information to emergency managers.

3. DATA AND METHODS

Our analyses incorporate national composites, or summaries, of WSR–88D radar reflectivity data for the period of 1996–2000, which we obtained from the Global Hydrology Resource Center. The radar data have a pixel size of 2 km × 2 km and represent the highest measured reflectivity in each pixel’s vertical column over a 15–minute period, binned in 5–dBZ increments. The data are available over the continental U.S. at 15–minute intervals. In addition to the actual reflectivity values, we also specifically keep track of the number echoes that exceed 40 dBZ in each 15–minute summary. For the purposes of discussion in this article, we henceforth call each echo that is $\geq$ 40 dBZ a storm element (or, more concisely, a *storm*), and call each 15–minute radar summary a *time*. These radar data are ideal for the present work because of their national coverage, regular grid, and the fact that many interested weather enthusiasts observe approaching convective storms using operational radar imagery.

We compute statistics and plot the radar data over several square arrays, centered on each target site, that represent familiar geopolitical entities. A square that is 274 km × 274 km = 75076 km^2 approximates the size of a typical National Weather Service county warning area (i.e., the area of the U.S. divided by the number of county warning areas, hereafter abbreviated as CWA). A square that is 54 km × 54 km = 2916 km^2 approximates the size of a typical county in the U.S. A square that is 14 km × 14 km = 196 km^2 approximates the size of a moderately large city (roughly 8.7 mi × 8.7 mi). Within this article, points within the square arrays are identified by their locations with respect to the target point, which has coordinates of $x = 0$, $y = 0$.

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We plot and discuss three primary statistics in this article. First, we utilize the lagged correlation between $dBZ(x,y,t)$ and $dBZ(0,0,t+\Delta t)$, where Δt is alternately taken to be 0, 15, 30, 45, 60, 75, 90, 105, and 120 min. In addition, for the binary variable i_{40}, defined by

$$i_{40} = \begin{cases} 1 & \text{when} \quad dBZ \geq 40 \\ 0 & \phantom{\text{when}} \quad dBZ < 40 \end{cases}, \tag{1}$$

we compute the following two statistics, at each point in the target array, for the n times in the 5–year period:

$$\mathrm{Pr}_{\mathrm{storm}} = \frac{1}{n}\sum_{t=1}^{n} i_{40}\left(x,y,t\right), \tag{2}$$

the probability that point (x,y) has a storm at a randomly selected time, and

$$\mathrm{Pr}_{\mathrm{hit|storm}} = \frac{\sum_{t=1}^{n} i_{40}\left(x,y,t\right)\cdot i_{40}\left(0,0,t+\Delta t\right)}{\sum_{t=1}^{n} i_{40}\left(x,y,t\right)}, \tag{3}$$

the normalized probability that, when a storm at point (x,y) occurs, a storm at the target also occurs Δt later (as before, with Δt taken in 15–min intervals between 0 and 120 min).

In our search for weather holes and hot spots, $\mathrm{Pr}_{\mathrm{storm}}$ reveals whether the target receives comparatively more or fewer storms than the surrounding region; $\mathrm{Pr}_{\mathrm{hit|storm}}$ reveals whether, when a location within the surrounding region has a storm, the target tends to be hit or missed; and the lagged correlations reveal the primary directions from which high–dBZ echoes arrive at the target. Although we compute these variables for numerous values of Δt, in this article we focus on $\Delta t = 60$ min, for brevity. Our analyses of $\mathrm{Pr}_{\mathrm{hit|storm}}$ in this article focus largely on radii smaller than or equal to 80 km. For $\Delta t = 60$ min, this radius limits the data to storms moving no faster than 80 km h^{-1}; it also represents the radius within which $\mathrm{Pr}_{\mathrm{hit|storm}}(\Delta t = 60$ min) was visibly different from $\mathrm{Pr}_{\mathrm{hit|storm}}(\Delta t = 0$ min).

Because meteorologists are often suspicious that they live in weather holes (or, among the more superstitious, that they *cause* them), we selected the following target sites (which have large communities of meteorologists) for detailed study: Albany, NY (ALB); Ann Arbor, MI (ARB); Urbana–Champaign, IL (CMI); College Station, TX (CLL); Fort Collins, CO (FCL); Grand Forks, ND (GFK); Huntsville, AL (HSV); Lincoln, NE (LNK); Los Angeles, CA (LAX); Lubbock, TX (LBB); Madison, WI (MSN); Norman, OK (OUN); Raleigh–Durham, NC (RDU); Salt Lake City, UT (SLC); Seattle, WA (SEA); Tallahassee, FL (TLH); Tucson, AZ (TUS); and State College, PA (UNV). For brevity, we hereafter refer to these sites by their 3–letter identifiers.

4. WHAT IS A WEATHER HOLE, REALLY?

By definition, a convective weather hole must receive fewer convective echoes than its surroundings. Accordingly, locations with low mean values of $\mathrm{Pr}_{\mathrm{storm}}$ are not necessarily weather holes; they may simply reside within regions in which convection is scarce. These may be dull places to live, but they are not "missed" by convective storms on the regional scale in any recurring way.

Rather, evidence of a weather hole must comprise both of the following: a) a value of $\mathrm{Pr}_{\mathrm{storm}}$ that is notably lower than that surrounding county and CWA, and b) upstream values of $\mathrm{Pr}_{\mathrm{hit|storm}}$ that are notably lower than for target sites in other parts of the nation. A combination of these effects is taken to mean that not only does the target city receive fewer convective echoes than its surroundings, but also that this is at least partly a symptom of approaching storms that do not hit the target site.

In this study, the subjectively chosen criteria for a weather hole are taken to be both: a) either $\mathrm{Pr}_{\mathrm{storm}}$ that is 10% lower than the surrounding county or that is 20% lower than the surrounding CWA, and b) $\mathrm{Pr}_{\mathrm{hit|storm}}$ that is at least one standard deviation lower than the mean value for all 18 target cities. The criteria for a weather hot spot are that the statistics for a site be higher than those for its surroundings and the other target cities by the same margins.

5. RESULTS

A representative pair of plots for $\Delta t = 60$ min is shown in Figs. 1 and 2, for ARB. The target, ARB, resides within a region of fairly homogeneous storm occurrence (Fig. 1): at any given pixel, about 0.36% of the 15–minute summaries included a convective echo (i.e., about 1 of every 278 summaries, or about 126 summaries per year). The 1–hour lagged dBZ correlation reveals that high–dBZ echoes most frequently arrive at ARB from the west–southwest (contoured in both Figs. 1 and 2). The $\mathrm{Pr}_{\mathrm{hit|storm}}$ (Fig. 2) shows that echoes from the upstream region (e.g., that encircled by the correlation=0.6 contour) are followed in 1 hour by a storm at ARB between 15 and 20% of the time, and that there are no areas to the west from which echoes seem to hit or miss ARB significantly more frequently. All of these features, taken together, suggest that convective behavior in ARB is not significantly different from that nearby, and thus that ARB is neither a weather hole nor hot spot. ARB is offered here as a benchmark because its data are fairly representative of the average target site. Indeed, the plots for CMI, LNK, MSN, and RDU (not shown) are quite similar.

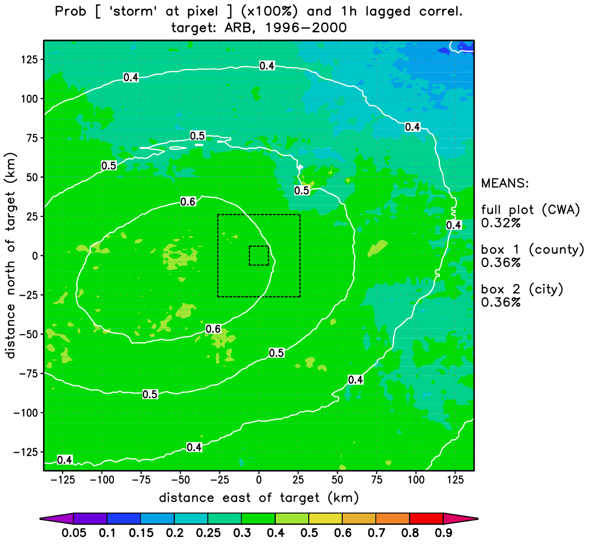

Figure 1: For target site ARB: $\mathrm{Pr}_{\mathrm{storm}}$, the probability that a pixel has a storm (an echo $\geq$ 40 dBZ) at any given time, expressed as a percentage and shaded; and 1–hour lagged correlation between a pixel's radar reflectivity and the target's radar reflectivity, contoured. The figure is the size of a CWA in this study; the smaller dashed boxes are the county and city averaging areas.

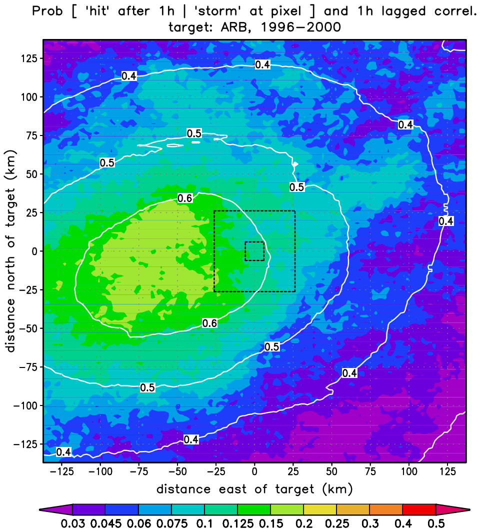

Figure 2: For target site ARB: $\mathrm{Pr}_{\mathrm{hit|storm}}$, the probability that a storm at a pixel is followed in 1 hour by a storm at the target, shaded; and 1–hour lagged correlation as in Fig. 1, contoured. The figure is the size of a CWA in this study; the smaller dashed boxes are the county and city averaging areas.

In order to present a reasonably small number of figures in this paper, we only present those such as Figs. 1 and 2 when they illustrate distinct classes of radar signatures. Following this overview, we discuss overall statistics that summarize all 18 target sites.

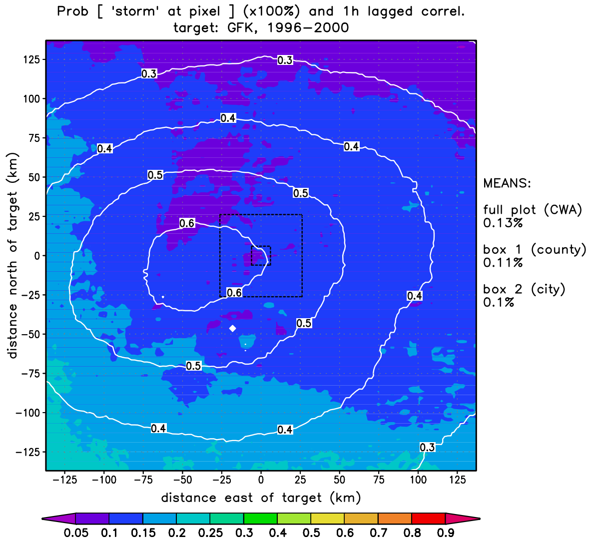

Figure 3: Same as Fig. 1, but for target site GFK.

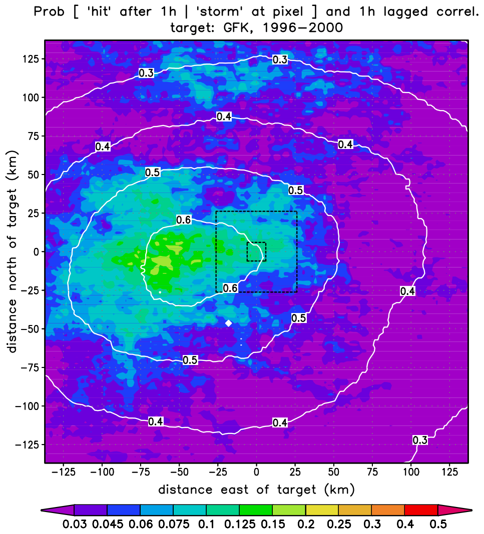

Figure 4: Same as Fig. 2, but for target site GFK.

The only site that meets both of the criteria for being called a weather hole in this study is GFK. This is demonstrated in Fig. 3 by its comparatively low values of $\mathrm{Pr}_{\mathrm{storm}}$ with respect to both its surrounding county and CWA, and in Fig. 4 by its upstream values of $\mathrm{Pr}_{\mathrm{hit|storm}}$, which are notably smaller than those for ARB in Fig. 2. Not only are convective echoes rare in GFK, but it resides in a regional minimum and does not receive storms frequently even when there is convection upstream. More details about the statistics for GFK will be addressed later.

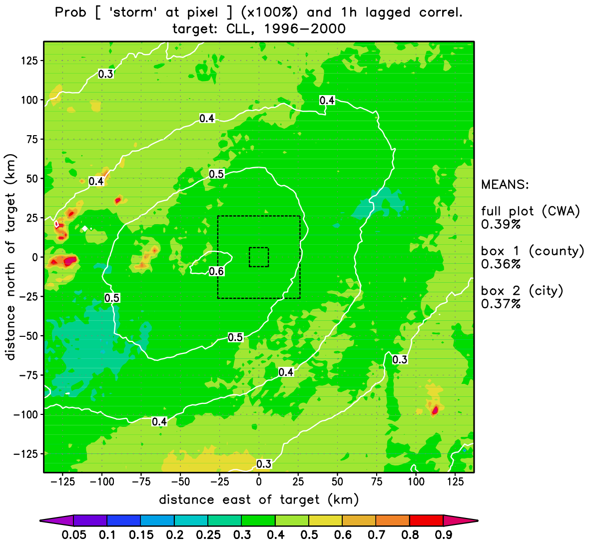

Figure 5: Same as Fig. 1, but for target site CLL.

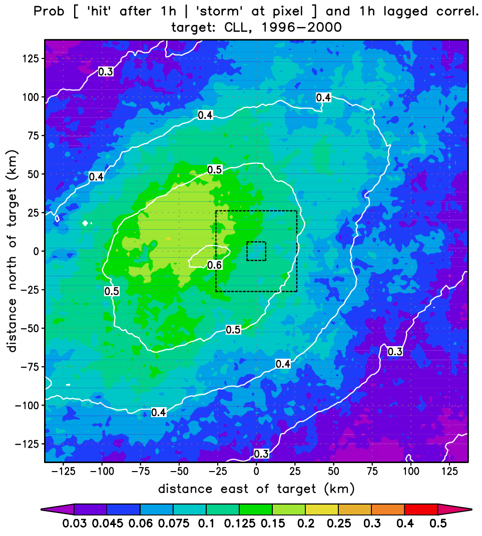

Figure 6: Same as Fig. 2, but for target site CLL.

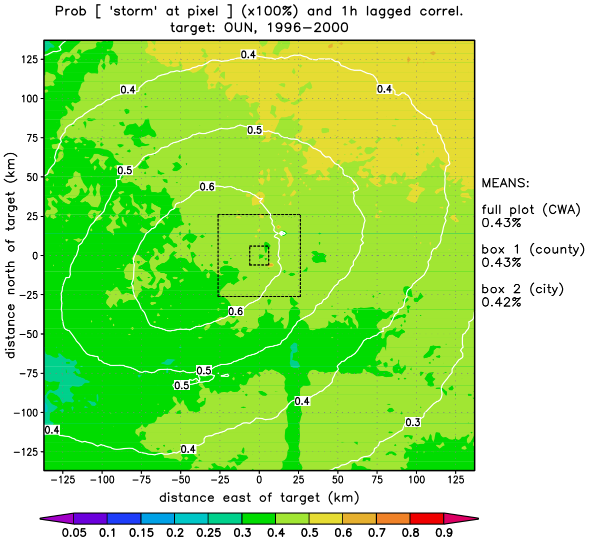

Figure 7: Same as Fig. 1, but for target site OUN.

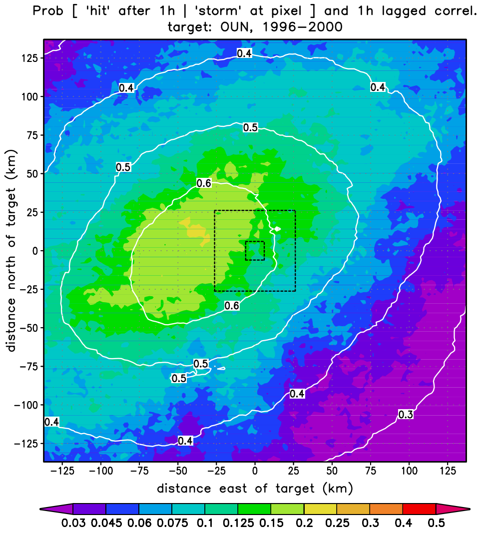

Figure 8: Same as Fig. 2, but for target site OUN.

Target site CLL is an example for which the local minimum in $\mathrm{Pr}_{\mathrm{storm}}$ might suggest that it is a weather hole (compared to regions northwest and southeast, Fig. 5), but its upstream values of $\mathrm{Pr}_{\mathrm{hit|storm}}$ are quite similar to those for ARB (cf. Figs. 6 and 2). Such stations are not properly called weather holes according to our definition.

Target site OUN has a mean $\mathrm{Pr}_{\mathrm{storm}}$ that is quite close to those of its surroundings (Fig. 7), and indeed appears to have a slightly higher value than the areas to its west–southwest, from which the lagged correlations indicate that echoes arrive. Additionally, on its upstream side, OUN has values of $\mathrm{Pr}_{\mathrm{hit|storm}}$ that are slightly higher than those of the ARB benchmark (cf. Figs. 8 and 2), hence OUN seems to be a slightly favorable location for convection. The plots for HSV, LBB, and TLH (not shown) are quite similar to those for OUN.

The data from LAX depict a region with few storms (Fig. 9), and one in which the presence of mountains slightly biases the data. Convective echoes are slightly more frequent over the high terrain (25–50 km north of the target in Fig. 9), beyond which poor radar coverage

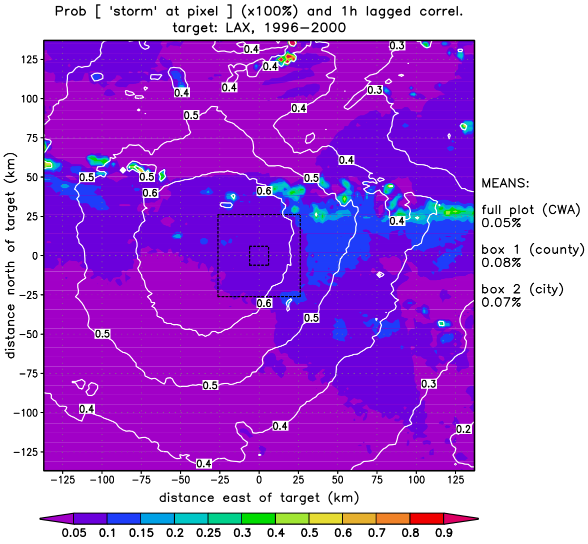

Figure 9: Same as Fig. 1, but for target site LAX.

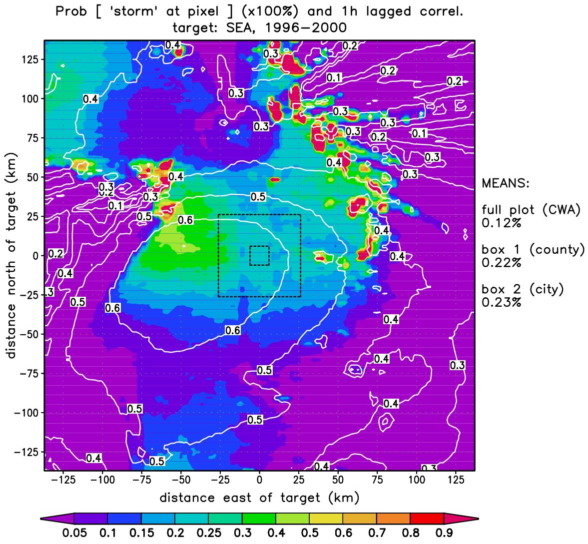

Figure 11: Same as Fig. 1, but for target site SEA.

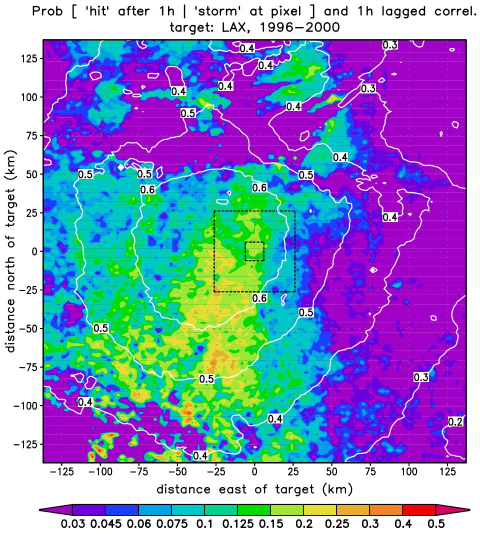

Figure 10: Same as Fig. 2, but for target site LAX.

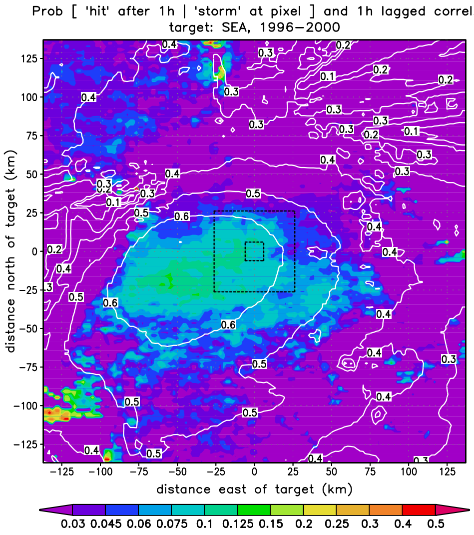

Figure 12: Same as Fig. 2, but for target site SEA.

may partly account for the dearth of convective echoes. In regions with relatively few storms, the values for $\mathrm{Pr}_{\mathrm{hit|storm}}$ are fairly noisy (Fig. 10), in part because the small number of storms at these pixels makes for minuscule sample sizes. Data for FCL are similar (not shown). It does appear that storms to the south of LAX, although rare, are frequently followed by storms at LAX.

The problem of mountains, taken to a greater length, is illustrated by the data for SEA in Figs. 11 and 12. The data appear to be reasonable in the broad region surrounding Puget Sound (roughly –50 to 25 km north and –75 to 25 km east) but are otherwise negatively affected by the Olympic Mountains to the west and Cascades to the east. The value for $\mathrm{Pr}_{\mathrm{storm}}$ at SEA is comparable to those for the surrounding county, and considerably larger than those for the CWA, in part because of the beam blockage by the mountain ranges (Fig. 11); Fig. 12 reveals that $\mathrm{Pr}_{\mathrm{hit|storm}}$ for Puget Sound are lower than for the ARB benchmark, suggesting local hole–like behavior. The data for SLC and TUS display similar complexities (not shown).

Despite the aforementioned problems in complex ter-

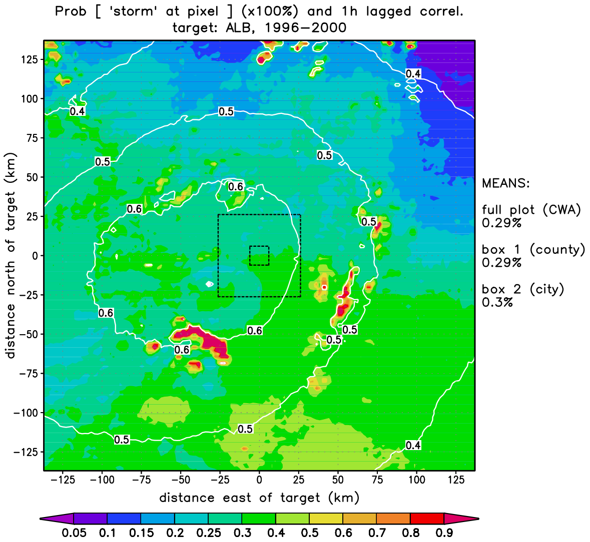

Figure 13: Same as Fig. 1, but for target site ALB.

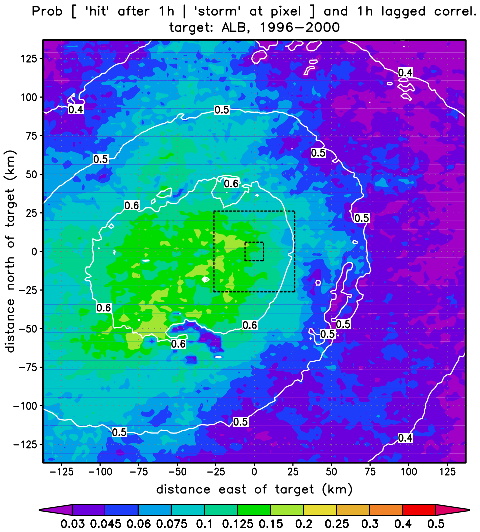

Figure 14: Same as Fig. 2, but for target site ALB.

rain, in the Appalachians the present technique appears nevertheless to be effective. For example, near ALB (Figs. 13 and 14), the presence of maxima in $\mathrm{Pr}_{\mathrm{storm}}$ is obvious, and apparently related to nearby mountains. However, there are not precipitous decreases in $\mathrm{Pr}_{\mathrm{storm}}$ beyond these features (Fig. 13), suggesting that beam blockage is not complete or perpetual, and perhaps indicating that part of the maxima in $\mathrm{Pr}_{\mathrm{storm}}$ is accounted for by orographic convection. In this case, therefore, the technique reveals an upstream $\mathrm{Pr}_{\mathrm{hit|storm}}$ to the southwest of ALB that is only slightly smaller in magnitude than that for ARB. To a lesser degree, data for UNV also exhibit this behavior (not shown).

To compare all of the sites simultaneously, we have summarized data from all 18 targets in Tables 1 and 2, and in Fig. 15. Table 1 compares $\mathrm{Pr}_{\mathrm{storm}}$ within the three predefined averaging areas, and Table 2 compares $\mathrm{Pr}_{\mathrm{hit|storm}}$ averaged for all azimuthal directions and all distances from the target between 10 and 80 km. Fig. 15 expands upon Table 2 by showing the azimuthally averaged $\mathrm{Pr}_{\mathrm{hit|storm}}$ as a function of distance from each city.

Fig. 15 shows that, for all 18 stations, $\mathrm{Pr}_{\mathrm{hit|storm}}$ decays radially at about the same rate, such that the radial average for each site fairly represents the general behavior of the locality. The azimuthal average seems to account well for the spatially distributed values of $\mathrm{Pr}_{\mathrm{hit|storm}}$ in that it includes nearby echoes in every direction, all of which would catch the attention of a radar–watching weather enthusiast and contribute to his/her subjective impression of whether a site is a weather hole. This approach is hindered only somewhat for the stations that reside within or near very mountainous terrain (i.e., FCL, LAX, SEA, SLC, and TUS), where there may be small azimuthal ranges with exceedingly large or small values of $\mathrm{Pr}_{\mathrm{hit|storm}}$.

Following Table 1, it is clear that only GFK has a local $\mathrm{Pr}_{\mathrm{storm}}$ that is significantly lower than those in both its county and CWA (a possible hole), although UNV is close on both counts. On the other hand, only FCL has a local $\mathrm{Pr}_{\mathrm{storm}}$ that is significantly higher than those in both its county and CWA (a possible hot spot). Four target sites, LAX, SEA, SLC, and TUS share the quality that, despite being statistically similar to their surrounding county (or more than 10% lower in the cases of LAX and TUS), they each have a significantly higher $\mathrm{Pr}_{\mathrm{storm}}$ than their CWAs. This is partly a symptom of beam blockage by mountains, beyond which the mean $\mathrm{Pr}_{\mathrm{storm}}$ is dramatically and artificially smaller. All of the other target sites appear to correspond fairly well with their regional background values, suggesting that they are neither weather holes nor hot spots.

Table 2 makes it clear that FCL is not a hot spot, despite the opposite implication of Table 1, because, on average, convection in the region is not likely to be followed by convection at the site. Hence, the data in Table 1 cannot stand alone in the diagnosis of weather holes or hot spots. The other mountainous stations, LAX, SEA, SLC, and TUS, also have lower than average values for $\mathrm{Pr}_{\mathrm{hit|storm}}$, revealing that they are not hot spots despite having higher values for $\mathrm{Pr}_{\mathrm{storm}}$ than their surrounding CWAs.

However, Table 2 does confirm that, not only does GFK have a low mean $\mathrm{Pr}_{\mathrm{storm}}$ compared to its surroundings, but it also has a mean 10–80 km $\mathrm{Pr}_{\mathrm{hit|storm}}$ that is a standard deviation lower than the sample mean. In

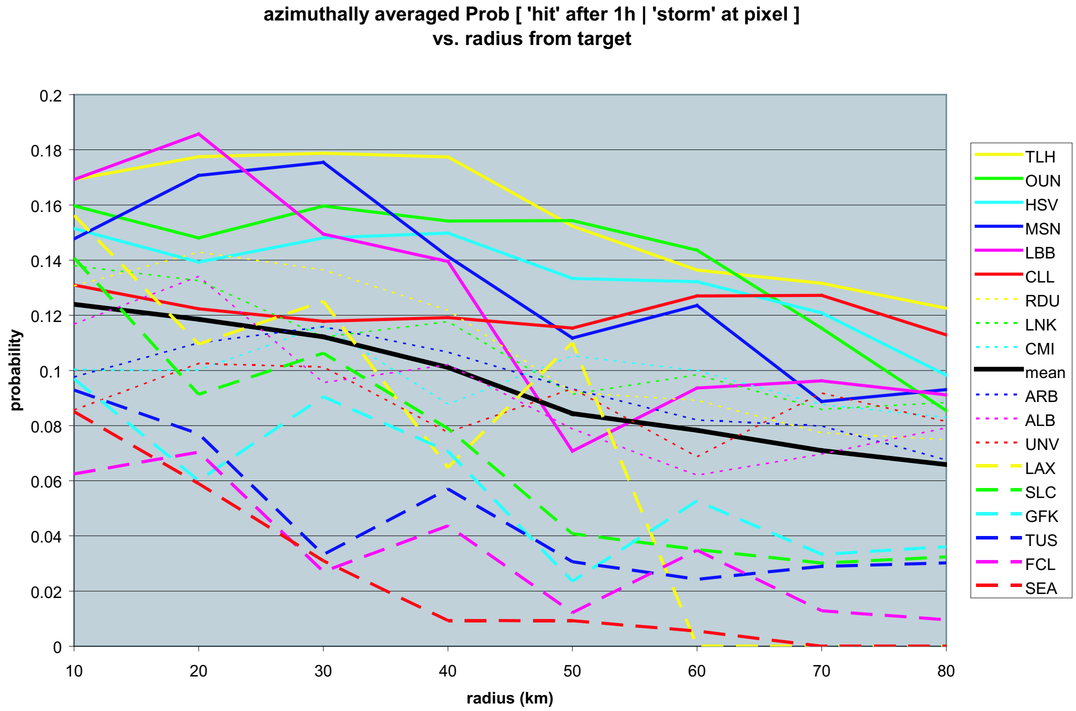

Figure 15: Azimuthally averaged $\mathrm{Pr}_{\mathtt{hit|storm}}$ for each of 18 target sites, expressed as a function of distance from the target site.

city identifier	"storm" frequency (% of summaries)		
	city	city–county	city–CWA
(10) ALB	0.30	+0.01	+0.01
(7) ARB	0.36	0.00	+0.04
(6) CLL	0.37	+0.01	–0.02
(5) CMI	0.41	+0.01	+0.02
(14) FCL	0.15	+0.03 (+20%)	+0.05 (+33%)
(16) GFK	0.10	–0.01 (–10%)	–0.03 (–30%)
(2) HSV	0.50	+0.01	–0.03
(18) LAX	0.07	–0.01 (–14%)	+0.02 (+29%)
(11) LBB	0.24	–0.01	–0.01
(9) LNK	0.33	+0.01	+0.01
(8) MSN	0.34	0.00	+0.02
(4) OUN	0.42	–0.01	–0.01
(3) RDU	0.44	+0.01	+0.03
(12) SEA	0.23	+0.01	+0.11 (+48%)
(17) SLC	0.09	0.00	+0.05 (+56%)
(1) TLH	0.69	–0.02	+0.04
(14) TUS	0.15	–0.02 (–13%)	+0.05 (+33%)
(13) UNV	0.22	–0.02	–0.04

Table 1: $\mathrm{Pr}_{\mathtt{storm}}$, expressed as percentages of total radar summaries, for the target city (column 2), and differences between the target city and its county (column 3) and CWA (column 4). Differences in column 3 that exceed 10% of the city value are denoted, as are differences in column 4 that exceed 20%. Cities are ranked by $\mathrm{Pr}_{\mathtt{storm}}$ in parentheses on the left side of column 1.

city identifier	mean 1–hr hit probability	≥ 1 std. deviation?
(11) ALB	0.092	
(10) ARB	0.094	
(6) CLL	0.122	
(9) CMI	0.098	
(17) FCL	0.034	–
(15) GFK	0.058	–
(3) HSV	0.134	+
(13) LAX	0.071	
(5) LBB	0.124	
(7) LNK	0.108	
(4) MSN	0.132	+
(2) OUN	0.140	+
(7) RDU	0.108	
(18) SEA	0.025	–
(14) SLC	0.069	
(1) TLH	0.156	+
(16) TUS	0.047	–
(12) UNV	0.088	
mean	0.094	

Table 2: Azimuthally and radially averaged $\mathrm{Pr}_{\mathtt{hit|storm}}$ between 10 and 80 km radius for each of 18 target sites. The sample's standard deviation is 0.036. Values that are more than one standard deviation above or below the mean are marked. Cities are ranked by $\mathrm{Pr}_{\mathtt{hit|storm}}$ in parentheses on the left side of column 1.

other words, GFK seems to receive fewer storms than its surroundings, and storms in its vicinity are often not followed by storms at GFK; this is the essence of a weather hole.

Other target sites that have significantly elevated values of $\mathrm{Pr}_{\mathrm{hit|storm}}$ include HSV, MSN, OUN, and TLH, although they do not meet the $\mathrm{Pr}_{\mathrm{hit|storm}}$ criterion to be considered hot spots. Nevertheless, TLH ranks first both in terms of $\mathrm{Pr}_{\mathrm{storm}}$ and $\mathrm{Pr}_{\mathrm{hit|storm}}$, suggesting that it is a prime location for convective storms. HSV and OUN are not far behind.

6. SUMMARY

Our preliminary work shows that there is indeed mesoscale variability in the frequency of convective echoes (i.e., $\geq$ 40 dBZ) in the vicinities of the 18 cities we selected for study. However, locations with low mean frequencies of convective echoes are not necessarily weather holes. When evaluated statistically, most of the selected sites in this study do not meet the multiple subjective criteria for being a weather hole, even though many meteorologists in these cities probably think that they live in weather holes. Apart from several cities that are situated near complicated terrain, for which results are still somewhat unclear, only Grand Forks, ND solidly meets our definition of a weather hole. None of the 18 locations solidly meet the definition of a weather hot spot, although Tallahassee, FL has the highest mean frequency of convective echoes and the greatest probability that storms within 80 km are followed by a storm in the city 1 hour later, making it the most favorable site among the 18 in which to experience stormy weather.

This study does not attempt to account for biases that might be introduced by sites' varying distances from the operational radars, although the composite data should minimize this effect somewhat. The study also does not attempt to remove the effects of non–convective echoes that exceeded 40 dBZ, such as in melting layers or from ground clutter, nor does it systematically address the problem of beam blocking in complex terrain.

Future studies may address these problems along the way toward constructing local climatologies of convective echoes in various regions, which may be useful in improving the public's awareness of severe weather risks and in estimating the probability that existent storms will strike populated areas.