Project Report
ATC-425

Revised Multifunction Phased Array Radar (MPAR) Network Siting Analysis

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16. Abstract

As part of the NextGen Surveillance and Weather Radar Capability (NSWRC) program, the Federal Aviation Administration (FAA) is currently developing the solution for aircraft and meteorological surveillance in the future National Airspace System (NAS). A potential solution is a multifunction phased array radar (MPAR) that would replace some or all of the single-purpose radar types used in the NAS today. One attractive aspect of MPAR is that the number of radars deployed would decrease, because redundancy in coverage by single-mission sensors would be reduced with a multifunction system. The lower radar count might then result in overall life cycle cost savings, but in order to estimate costs, a reliable estimate of the number of MPARs is needed.

Thus this report addresses the question, "If today's weather and aircraft surveillance radars are replaced by a single class of multimission radars, how many would be needed to replicate the current air space coverage over the United States and its territories?" Various replacement scenarios must be considered, since it is not yet determined which of the organizations that own today's radars (the FAA, the National Weather Service (NWS), the different branches of the U.S. military) would join in an MPAR program. It updates a previous study using a revised set of legacy systems, including 81 additional military airbase radars.

Six replacement scenarios were considered, depending on the radar mission categories. Scenario 1 would replace terminal radars only, i.e., the Airport Surveillance Radars (ASRs) and the Terminal Doppler Weather Radar (TDWR). Scenario 2 would include the Scenario 1 radars plus the long-range weather radar, commonly known as NEXRAD. Scenario 3 would add the long-range aircraft surveillance radars, i.e., the Air Route Surveillance Radars (ARSRs), to the Scenario 2 radars. To each of these three scenarios, we then add the military's Ground Position Navigation (GPN) airbase radars for Scenarios 1G, 2G, and 3G.

We assumed that the new multimission radar would be available in two sizes—a full-size MPAR and a scaled-down terminal MPAR (TMPAR). Furthermore, we assumed that the new radar antennas would have four sides that could be populated by one, two, three, or four phased array faces, such that the azimuthal coverage provided could be scaled from 90° to 360°. Radars in the 50 United States, Guam, Puerto Rico, U.S. Virgin Islands, Guantanamo Bay (Cuba), and Kwajalein (Marshall Islands) were included in the study.

Our analysis results can be summarized in the following bar graph and table.

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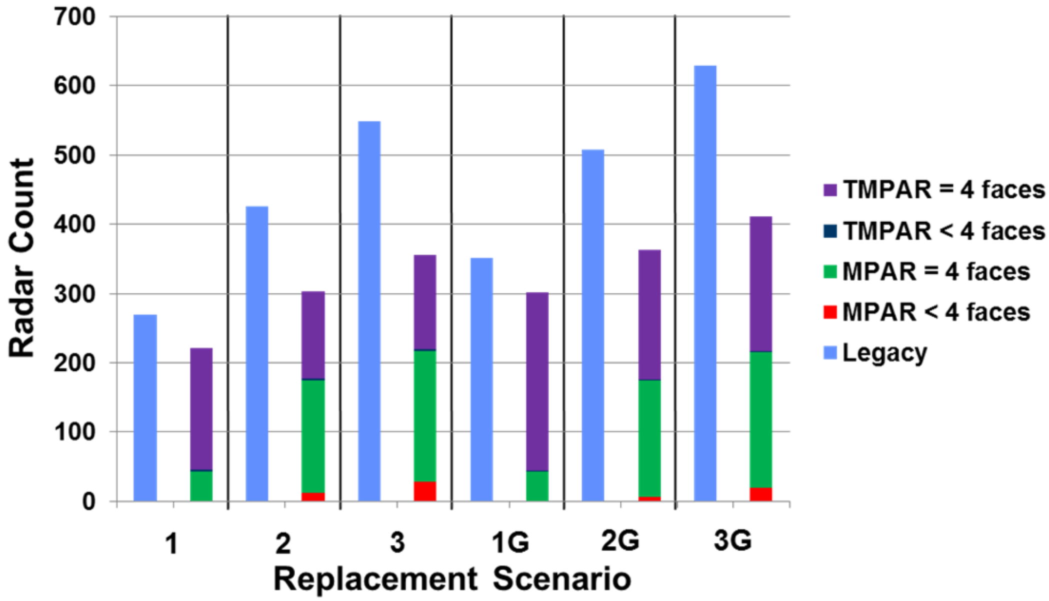
EXECUTIVE SUMMARY

As part of the NextGen Surveillance and Weather Radar Capability (NSWRC) program, the Federal Aviation Administration (FAA) is currently developing the solution for aircraft and meteorological surveillance in the future National Airspace System (NAS). A potential solution is a multifunction phased array radar (MPAR) that would replace some or all of the single-purpose radar types used in the NAS today. One attractive aspect of MPAR is that the number of radars deployed would decrease, because redundancy in coverage by single-mission sensors would be reduced with a multifunction system. The lower radar count might then result in overall life cycle cost savings, but in order to estimate costs, a reliable estimate of the number of MPARs is needed.

Thus this report addresses the question, “If today’s weather and aircraft surveillance radars are replaced by a single class of multimission radars, how many would be needed to replicate the current air space coverage over the United States and its territories?” Various replacement scenarios must be considered, since it is not yet determined which of the organizations that own today’s radars (the FAA, the National Weather Service (NWS), the different branches of the U.S. military) would join in an MPAR program. It updates a previous study using a revised set of legacy systems, including 81 additional military airbase radars.

Six replacement scenarios were considered, depending on the radar mission categories. Scenario 1 would replace terminal radars only, i.e., the Airport Surveillance Radars (ASRs) and the Terminal Doppler Weather Radar (TDWR). Scenario 2 would include the Scenario 1 radars plus the long-range weather radar, commonly known as NEXRAD. Scenario 3 would add the long-range aircraft surveillance radars, i.e., the Air Route Surveillance Radars (ARSRs), to the Scenario 2 radars. To each of these three scenarios, we then add the military’s Ground Position Navigation (GPN) airbase radars for Scenarios 1G, 2G, and 3G.

We assumed that the new multimission radar would be available in two sizes—a full-size MPAR and a scaled-down terminal MPAR (TMPAR). Furthermore, we assumed that the new radar antennas would have four sides that could be populated by one, two, three, or four phased array faces, such that the azimuthal coverage provided could be scaled from 90° to 360°. Radars in the 50 United States, Guam, Puerto Rico, U.S. Virgin Islands, Guantanamo Bay (Cuba), and Kwajalein (Marshall Islands) were included in the study.



Reduction in Number of Radars

Scenario	Legacy	MPAR + TMPAR	Change	% Reduction
1	270	43 + 178 = 221	–49	18%
2	426	174 + 129 = 303	–123	29%
3	548	217 + 139 = 356	–192	35%
1G	351	43 + 258 = 301	–50	14%
2G	507	174 + 189 = 363	–144	28%
3G	629	215 + 196 = 411	–218	35%

For Scenario 1, the reduction in radar count comes from the elimination in coverage overlap of ASRs and TDWRs at TDWR airports. In Scenario 2, additional reduction results from removing the overlap between NEXRADs located near airports and the ASRs at those airports. Even more redundancy can be taken out in Scenario 3, because much of the en route coverage targeted by the ARSRs is already covered by the NEXRAD replacement from Scenario 2. Similar fractional radar count reductions are achieved when GPN sites are added.

Despite the reduction in radar count, the projected coverage volume for weather and aircraft surveillance would increase modestly for the MPAR network. This is an inevitable by-product of constraining ourselves to duplicating the existing coverage for both weather and aircraft surveillance. Comparing legacy to Scenario 3G coverage over all of the air space considered in this study, weather observation coverage would increase from 89% to 91% and aircraft surveillance coverage would improve from 71% to 81%. Peaks in coverage enhancement occur at altitude slices of 2,500 ft AGL for weather (35% to 50%) and 60,000 ft MSL for aircraft (83% to 100%).

In addition to the increase in coverage, the observation performance inside the coverage volume will improve due to the dual-polarization weather measurement and aircraft altitude finding capabilities of MPAR. (In contrast, only the NEXRAD has the former and the ARSR-4 has the latter capability among the legacy radars.) And even though the total radar counts would decrease, overlapping Doppler weather coverage will increase overall, which will benefit echo tops and wind vector determination. Comparing legacy to Scenario 3G over all of the air space considered in this study, overlapping Doppler weather coverage would increase from 59% to 75% and dual-polarization coverage would improve from 84% to 91%.

Terminal aircraft surveillance coverage would be strictly preserved under this MPAR siting scheme. Airports currently equipped with an ASR but no wind-shear observation system would gain wind-shear detection coverage through a TMPAR or MPAR. Airports currently equipped with an ASR but without a nearby NEXRAD would get high-quality dual-polarization Doppler weather data. On average, terminal air spaces will have more overlapping Doppler weather coverage, increased dual-polarization weather radar data, and gain the capability for aircraft altitude estimation.

Finally, low-altitude urban air space coverage will be improved with MPAR for all replacement scenarios. More overlapping Doppler weather radar coverage, better spatial resolution for weather and aircraft surveillance, and, most of all, enhancements in dual-polarization coverage and vertical accuracy of aircraft detection will be obtained compared to the legacy radar network.

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1. INTRODUCTION

As weather and aircraft surveillance radars age, they must be sustained through service life extension programs or be replaced. One possibility for the latter option is to replace the current single-mission radars with scalable multifunction phased array radars (MPARs) (Benner et al., 2009). State-of-the-art active phased array systems have the potential to provide improved capabilities such as earlier detection and better characterization of hazardous weather phenomena, 3D tracking of noncooperative aircraft, better avoidance of unwanted clutter sources such as wind farms, and more graceful performance degradation with component failure. As the U.S. aviation community works toward realizing the Next Generation Air Transportation System (NextGen), achieving improved capabilities for aircraft and weather surveillance becomes critical, because stricter observation requirements are believed to be needed (Souders et al., 2010). Hence, the Federal Aviation Administration (FAA) is considering the MPAR as a possible solution to their NextGen Surveillance and Weather Radar Capability (NSWRC).

Cost is a major hurdle to the deployment of a modern phased array radar network. One way of lowering the overall cost is to reduce the total number of radars. Because of the overlap in coverage provided by the current radar networks, a unified MPAR replacement network can potentially decrease the total number of radars needed to cover the same airspace. This problem was previously studied by MIT Lincoln Laboratory. Since then, however, the FAA has revised the list of Airport Surveillance Radars (ASRs) that would be candidates for replacement by MPAR. Furthermore, it was decided that the military-equivalent airbase surveillance systems should be included in separate scenarios as the military services may join as stakeholders for MPAR. Therefore, this study revisits the siting analysis using an updated list of legacy radars. The aim is to provide an estimate of the minimum number of MPARs needed to replace the existing radar coverage. We will also provide a statistical compilation of legacy versus MPAR coverage for various observational performance parameters.

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2. ASSUMPTIONS AND METHODOLOGY

The assumptions made in the analysis has not changed since the previous study except for the change in the list of FAA ASRs and the inclusion of military airbase radars, but we will list them here for easy reference.

- Legacy radars included in the study were the ASRs, the military-equivalent Ground Position Navigation (GPN) systems, Air Route Surveillance Radars (ARSRs), Terminal Doppler Weather Radar (TDWR), and Next Generation Weather Radar (NEXRAD).
- Only operational radars were included (e.g., no support and training facility radars).
- Domain of interest was all 50 states plus U.S. territories that have any relevant legacy radars. (No radars under foreign control were included.)
- Relevant legacy radars in domain of interest were included regardless of owner (Department of Commerce, Department of Defense, and Department of Transportation).
- Study was conducted relative to existing weather and surveillance requirements (not future NextGen requirements).
- Secondary radars and their requirements were not included.
- Performance characteristics of the legacy radars were based on completion of all ongoing and planned upgrades.
- Two sizes of MPARs were used: full size (MPAR) and terminal (TMPAR).
- MPAR/TMPAR sites were limited to existing radar sites.
- Antenna heights were constrained to the height of the existing antenna.
- Current operational elevation angle coverages were used for the legacy radars. MPAR/TMPARs were assumed to have 0° to 60° elevation coverage when sited at non-ARSR-4 sites. At ARSR-4 sites, MPAR/TMPAR coverage was assumed to extend from –7° to 60° elevation.
- MPARs and TMPARs were assumed to be scalable in azimuthal coverage. In other words, the basic building block would be a planar array covering 90° in azimuth. Thus, an MPAR could have one to four faces with corresponding azimuthal coverage of 90°, 180°, 270°, and 360°.

Terrain and structural blockages were calculated using the Shuttle Radar Tomography Mission (SRTM) Level 1 data as the primary elevation data source. Where SRTM was unavailable, we used the Level 1 Digital Terrain Elevation Data (DTED). Beam propagation geometry assumed the 4/3-Earth-radius model to account for atmospheric refraction (e.g., Skolnik, 2008). Radar coverage parameters were computed at 1/120 deg (lat/lon) horizontal and variable vertical resolution (100 ft for 0–10,000 ft MSL, 1,000 ft for 11,000–25,000 ft MSL, 5,000 ft for 30,000–70,000 ft MSL, and 10,000 ft for 80,000–100,000 ft MSL). Radar range coverage extent was determined by the instrumented range or the range at which the target sensitivity equaled the threshold value, whichever was shorter. We chose a sensitivity threshold of 1 m^2 for aircraft and 5 dBZ for weather. (The exact values used are not crucial as this is a comparative analysis.)

Note, also, that we used the top-of-tower height for the antenna height. The actual antenna feed height for a mechanically scanned dish will be a bit higher than the tower top and vary somewhat with elevation angle. The phase centers of the MPAR and TMPAR antennas would also be slightly higher than the tower top by some still undetermined amount. For the purposes of this comparative coverage analysis, the key factor is to use a consistent metric for all radars, which the tower height gives.

The legacy radar characteristics are listed in Table 2-1, while the assumed MPAR parameters are shown in Table 2-2. The GPN models are the military equivalent of the ASR series (GPN-20 = ASR-8, GPN-27 = ASR-9, GPN-30 = ASR-11). The NEXRAD has recently been upgraded with dual-polarization capability (Istok et al., 2009), while the TDWR has been retrofitted with an enhanced radar data acquisition system (Cho and Weber, 2010). The ARSR-1, ARSR-2, ARSR-3, and the military-equivalent Fixed Position System (FPS) series are being updated through the Common ARSR (CARSR) program (Wang et al., 2009). Thirty-four out of 122 FAA ASR-9s have the Weather Systems Processor (WSP), which enables Doppler measurements for wind-shear detection (Weber, 2002). Other references for the legacy systems are as follows: NEXRAD (ROC, 2010), TDWR (Michelson et al., 1990), ASR-9 (Taylor and Brunins, 1985), ASR-11 (Raytheon, 1999), and ARSR-4 (Lay et al., 1990). Note that the formal name for NEXRAD is the Weather Surveillance Radar-1988 Doppler (WSR-88D).

TABLE 2-1

Legacy Radar Characteristics

Parameter	NEXRAD	TDWR	ASR/GPN	CARSR	ARSR-4
Minimum Observation Range	1 km	0.5 km	0.93 km	9.3 km	9.3 km
Maximum Observation Range	460 km	90 km[a]	110 km	444 km	463 km[b], 246 km[c]
Maximum Observation Range (Wx Doppler)	300 km	90 km	110 km[d]	N/A	N/A
Range Resolution (Wx)	0.25 km	0.15 km	0.93 km, 0.15 km[d]	0.46 km	0.46 km
Range Resolution (A/C)	N/A	N/A	0.23 km	0.23 km	0.23 km
Maximum Elevation Angle	19.5°	60°	N/A[e]	N/A[e]	5°[b], 30°[c]
Elevation Angle Resolution (Wx)	1° (0 < EL ≤6.2°) 1.3° (6.2 < EL ≤ 10°) 2° (10 < EL ≤ 14°) 2.8° (EL > 14°)[f]	0.6° (0 < EL ≤ 1°) 0.7° (1 < EL ≤ 2.6°) 1.6° (2.6 < EL ≤ 6.1°) 4.9° (EL > 6.1°)[g]	N/A	N/A	N/A
Azimuthal Resolution (Wx)[h]	1° (0 < EL < 2°) 1.4° (EL ≥ 2°)	1.2°	2°, 2.5°[d]	1.7°	1.7°
Azimuthal Resolution (A/C)	N/A	N/A	1.5°	1.5°	1.5°
Vertical RMS Accuracy at 175 nmi (A/C)	N/A	N/A	N/A	N/A	3,000 ft
Minimum Detectable Wx Reflectivity at 20 km	–18 dBZ	–19 dBZ[i]	–1 dBZ[j]	–8 dBZ	–9 dBZ
Maximum A/C Detection Range[k]	N/A	N/A	100 km (1 m^2)	430 km (2.2 m^2, FPSs) 380 km (2.2 m^2, ARSR-1,2,3)	420 km (1 m^2)

[a]Surface scan has maximum reflectivity range of 460 km.
[b]Low stack antenna beams.
[c]High stack antenna beams.
[d]For WSP output.
[e]Fixed elevation fan beam.
[f]From elevation beam spacing of Volume Coverage Pattern (VCP) 11.
[g]From elevation beam spacing of monitor volume scan.
[h]Includes scan broadening and data windowing effects.
[i]Sensitivity Time Control (STC) limits minimum detectable reflectivity to –26 dBZ for range <9 km.
[j]Sensitivity drops by 17 dB for range <12 km due to short pulse mode on ASR-11/GPN-30.
[k]Detection range varies with elevation angle.

TABLE 2-2

Assumed MPAR Characteristics

Parameter	MPAR	TMPAR
Minimum Observation Range	0.5 km	0.5 km
Maximum Observation Range	460 km	90 km
Range Resolution (Wx)	0.15 km	0.15 km
Range Resolution (A/C)	0.23 km	0.23 km
Maximum Elevation Angle	60°	60°
Elevation Angle Resolution (Wx)[a]	1°	2°
Azimuthal Resolution (Wx)[a]	1°	2°
Azimuthal Resolution (A/C)[a]	1°	2°
Vertical RMS Accuracy at 175 nmi (A/C)[b]	1,900 ft	3,700 ft
Minimum Detectable Wx Reflectivity at 20 km[c]	–19 dBZ	–1 dBZ
Maximum A/C Detection Range[c]	420 km (1 m^2)	100 km (1 m^2)

[a]These are approximate values. They will actually vary with scan angle.
[b]Assumes 1:10 monopulse improvement in intrabeam accuracy.
[c]These values are for horizon scans. They will be degraded with increasing elevation angle due to deliberate transmit beam widening that speeds up volume scan rates.

MPAR sensitivity at 0° elevation angle was assumed to equal the maximum ARSR-4 aircraft sensitivity and the TDWR's weather sensitivity (i.e., the best weather sensitivity of the legacy radars). TMPAR sensitivity at 0° elevation angle was assumed to equal the maximum ASR-9 aircraft sensitivity and a weather sensitivity of 7 dBZ at 50 km. The MPAR/TMPAR sensitivities were degraded with increasing elevation angle to account for the deliberate beam spoiling that decreases the volume scan time while maintaining the required power on target. They were also assumed to operate in a long pulse/short pulse mode, with the latter covering the short-range blind zone of the former. The transition range between the two modes was 6 km for MPAR and 2 km for TMPAR. The minimum detectable weather reflectivity for the short pulse mode was –14 dBZ at 6 km for MPAR and –14 dBZ at 2 km for TMPAR.

The numbers of legacy radars by type are given in Table 2-3, and maps of their locations are displayed in Figure 2-1. Note that of the 81 GPN sites, 16 actually have ASRs. The "GPN" categorization simply indicates primary ownership by the military. (None of the ASR sites have GPN radars.)

TABLE 2-3

Legacy Radar Count

NEXRAD	TDWR	ASRs	GPNs	CARSR	ARSR-4	Total
156	45	225	81	79	43	629

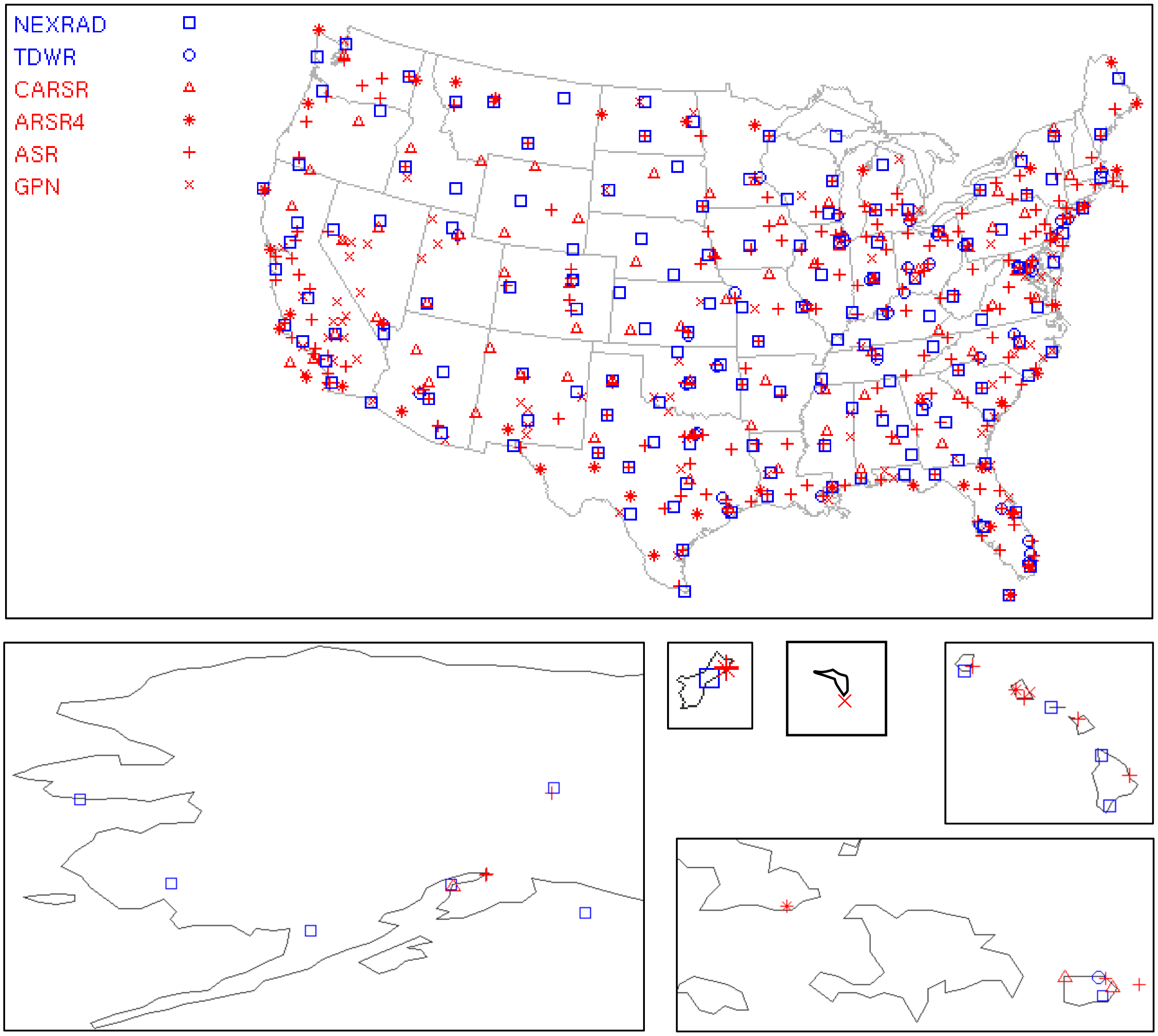

Figure 2-1. Locations of the legacy radars in the CONUS, Alaska, Guam, Kwajalein, Hawaii, and Puerto Rico/U.S. Virgin Islands/Guantanamo Bay.

Six replacement scenarios were examined. Scenario 1 had terminal radars only (ASRs and TDWRs). Scenario 2 included terminal radars and national-scale weather radars (ASRs, TDWRs, and NEXRADs). Scenario 3 had terminal radars, national-scale weather radars, and long-range aircraft surveillance radars (ASRs, TDWRs, NEXRADs, CARSRs, and ARSR-4s). Scenarios 1G, 2G, and 3G added the GPN sites to the first three replacement scenarios. In terms of stakeholders corresponding to the radars to be replaced, Scenario 1 is the FAA only, Scenario 2 is primarily the FAA and the National Oceanic and Atmospheric Administration (NOAA), and Scenario 3 adds the Air Force to the mix. For Scenarios 1G, 2G, and 3G, all the armed services branches are added to the Scenarios 1, 2, and 3 stakeholder compositions, respectively.

The basic procedure for selecting MPAR and TMPAR sites was to (1) compute the 3D weather and aircraft surveillance coverage provided by the legacy radars for each scenario, (2) start with a trial placement of new radars, (3) compare the new coverage with the legacy coverage, (4) add or subtract radars to better match the coverages, and (5) repeat steps 3 and 4 until coverage redundancy was minimized but legacy coverage was maintained.

For terminal area coverage, we took the conservative approach of essentially requiring every airport with an ASR to have at least a TMPAR, and TDWR airports to be covered by MPARs. The latter radars were sited at the airport ASR and not the TDWR off-airport location, so that low-altitude terminal aircraft coverage would not be compromised. This arrangement, however, moves the cone of silence over the airport, which may affect the ability of the microburst detection algorithm to mitigate false alarms by screening for storm-like reflectivity aloft (Huang et al., 2009). Fortunately, we were able to show that the cone of silence would be covered adequately by neighboring radars for this purpose (Cho et al., 2013). The choice of MPAR (instead of TMPAR) to cover TDWR airports stems from the uncertainty of whether a TMPAR would be able to match the wind-shear detection performance of TDWR. A recent study suggests that, for microburst detection, a TMPAR may be an acceptable replacement for TDWR at wet microburst sites; however, the range of gust front detection and tracking would be reduced (Cho et al., 2013). And, of course, dry microburst detection performance by a TMPAR would be much worse than with a TDWR, so a full-size MPAR should be placed at sites that experience dry microbursts.

For Scenario 2, we started with the Scenario 1 placements and added MPARs at NEXRAD sites that were not close to airports already covered in Scenario 1. We then focused on the 5,000 ft AGL level in weather coverage, because that is the level at which the NEXRAD network provides a nearly seamless coverage over flat terrain.

In Scenario 3, we began with the Scenario 2 placements and filled in gaps observed in en route aircraft coverage. Sometimes NEXRAD locations would be swapped with CARSR sites if better overall coverage could be generated. Along the national perimeter we preferentially used ARSR-4 sites over nearby NEXRAD sites to ensure that both low-altitude (down to 100 ft AGL) and long-range national border surveillance would remain unscathed as facilitated by the high-elevation location and look-down capability provided by the ARSR-4 sites. For the interior weather coverage, we again used the 5,000 ft AGL level coverage as an initial metric and the 10,000 ft level for en route aircraft coverage.

For Scenarios 1G, 2G, and 3G, we started with the respective scenarios without the GPN sites, then added TMPARs to the GPN sites. Wherever a GPN site could also be used to replace one of the MPAR sites, the MPAR site was removed and the TMPAR at the GPN site was replaced by an MPAR. The resulting coverages were checked and the siting adjusted if necessary in the manner described above until an optimal solution was reached.

At times, two sites that were very close together could not be replaced by one radar, because a large difference in altitude combined with high-relief terrain prevented the replication of the legacy coverage. In other instances, wedge-shaped coverage gaps were observed for which a full 360° azimuth radar would not be necessary. Unlike the legacy radars that mechanically rotate a single antenna in azimuth, the MPAR and TMPAR could be scaled down in coverage and cost by having less than the full number of antenna faces needed to observe all azimuths. Thus, we made the assumption that the new radars would be composed of planar antenna arrays that would cover a 90° azimuth sector each, and that five different configurations would be available (Figure 2-2). In the site placement procedure, we allowed the use of these five configurations positioned at any azimuthal orientation.

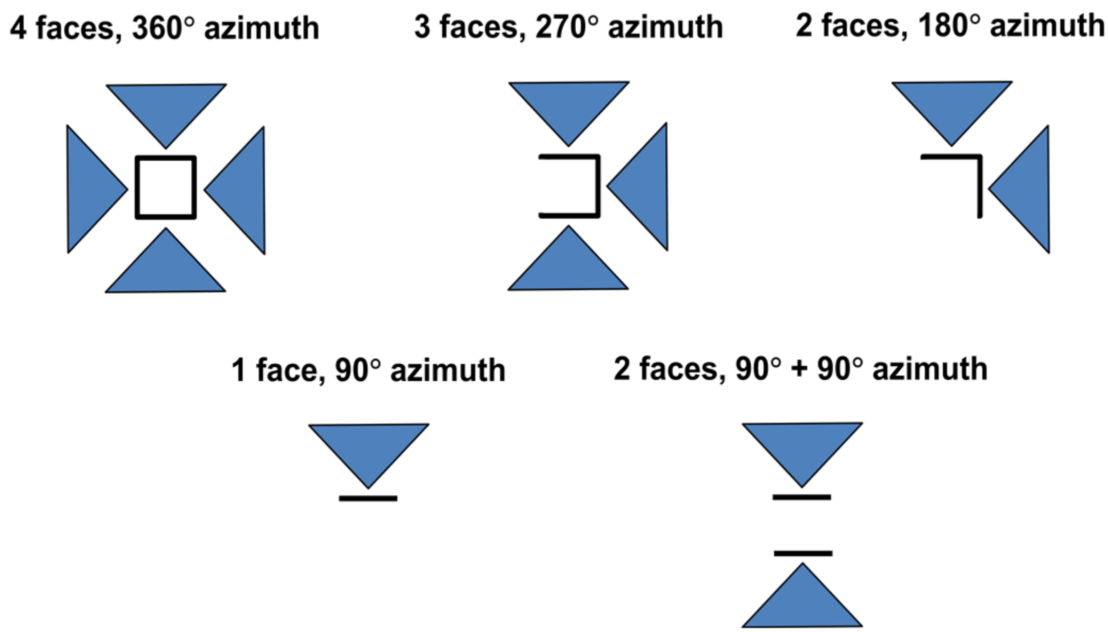

Figure 2-2. Illustration of MPAR and TMPAR coverage provided by each of the five possible antenna configurations.

This study is only a first-order siting analysis, used mainly for the purposes of planning and cost estimation. If the MPAR solution to NSWRC is officially adopted, then a more careful site-by-site analysis would have to be conducted for optimal (and feasible) placement of each radar.

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3. SITING ANALYSIS RESULTS

By constraining ourselves to duplicating the existing coverage for both weather and aircraft surveillance, the new multifunctional coverage inevitably improves upon the legacy coverage. This is because the existing weather and aircraft surveillance coverages do not occupy exactly the same airspace, and the multifunctional coverage is essentially the union of the two disparate volumes. Detailed statistical comparisons between legacy and proposed MPAR coverages are given in Section 4. In this section, we present the proposed siting results.

The site-by-site placement of MPARs and TMPARs, and the number of antenna faces on each, are tabulated in Appendix A. For number of faces less than four, the number of faces and the azimuthal coverage range (increasing clockwise from due north) are given in parentheses. The total radar counts are summarized by scenario in Tables 3-1 through 3-6. The reductions in the number of radars are listed in Table 3-7 and graphically displayed in Figure 3-1.

TABLE 3-1

Scenario 1: Legacy vs. MPAR/TMPAR Number of Radars

Type	Number of Faces				Total
	1	2	3	4	
Legacy	N/A	N/A	N/A	N/A	270
MPAR	0	0	0	43	43
TMPAR	0	2	1	175	178

TABLE 3-2

Scenario 2: Legacy vs. MPAR/TMPAR Number of Radars

Type	Number of Faces				Total
	1	2	3	4	
Legacy	N/A	N/A	N/A	N/A	426
MPAR	1	3	9	161	174
TMPAR	0	2	1	126	129

TABLE 3-3

Scenario 3: Legacy vs. MPAR/TMPAR Number of Radars

Type	Number of Faces				Total
	1	2	3	4	
Legacy	N/A	N/A	N/A	N/A	548
MPAR	1	11	16	189	217
TMPAR	0	2	1	136	139

TABLE 3-4

Scenario 1G: Legacy vs. MPAR/TMPAR Number of Radars

Type	Number of Faces				Total
	1	2	3	4	
Legacy	N/A	N/A	N/A	N/A	351
MPAR	0	0	0	43	43
TMPAR	0	2	0	256	258

TABLE 3-5

Scenario 2G: Legacy vs. MPAR/TMPAR Number of Radars

Type	Number of Faces				Total
	1	2	3	4	
Legacy	N/A	N/A	N/A	N/A	507
MPAR	1	1	5	167	174
TMPAR	0	2	0	187	189

TABLE 3-6

Scenario 3G: Legacy vs. MPAR/TMPAR Number of Radars

Type	Number of Faces				Total
	1	2	3	4	
Legacy	N/A	N/A	N/A	N/A	629
MPAR	1	6	11	197	215
TMPAR	0	2	0	194	196

TABLE 3-7

Reduction in Number of Radars

Scenario	Legacy	MPAR + TMPAR	Change	% Reduction
1	270	43 + 178 = 221	–49	18%
2	426	174 + 129 = 303	–123	29%
3	548	217 + 139 = 356	–192	35%
1G	351	43 + 258 = 301	–50	14%
2G	507	174 + 189 = 363	–144	28%
3G	629	215 + 196 = 411	–218	35%

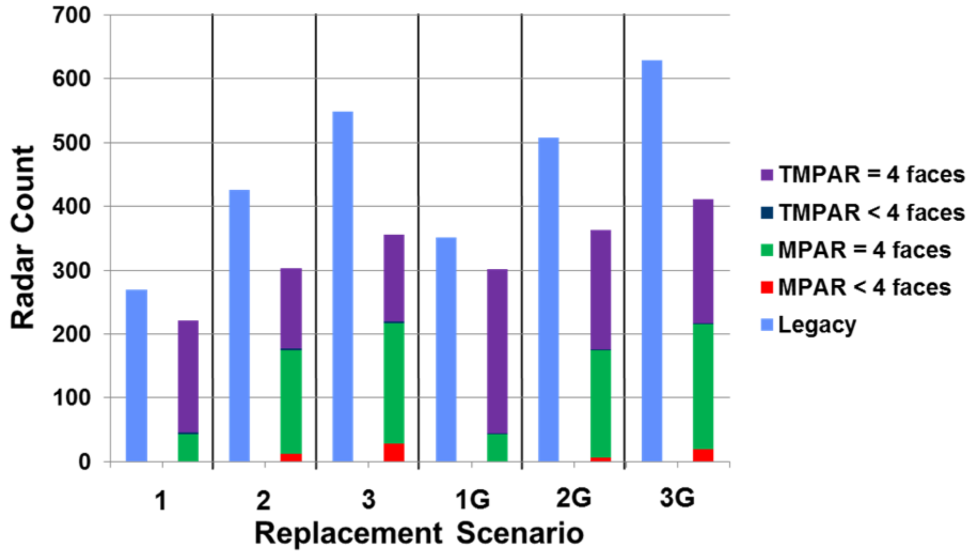

Figure 3-1. Total radar count vs. scenario.

For Scenarios 1 and 1G, the reduction in radar count mainly comes from the overlap of ASRs and TDWRs at TDWR airports. For Scenarios 2 and 2G, additional reductions result from NEXRADs located near airports (ASRs) and military airbases (GPNs). Even more redundancy can be eliminated in Scenarios 3 and 3G, because much of the en route coverage targeted by the CARSRs and ARSR-4s is already covered by the NEXRAD replacements from Scenarios 2 and 2G.

Although the minimum antenna beam elevation angle specification for the ARSR-4 is –7°, the lowest angle used in operation today is –3° (K. Roulston, private communication). Near-range legacy radar coverage may be affected by the difference in minimum elevation angle, so we reran the Scenario 3 siting analysis in regions with ARSR-4s. Because the minimum observation range of the ARSR-4 is 9.3 km, only sites that were more than ~1,600 ft above nearby terrain were affected. We concluded that our final siting set would remain the same. Finally, Figures 3-2 to 3-7 show maps of the MPAR and TMPAR locations for all replacement scenarios.

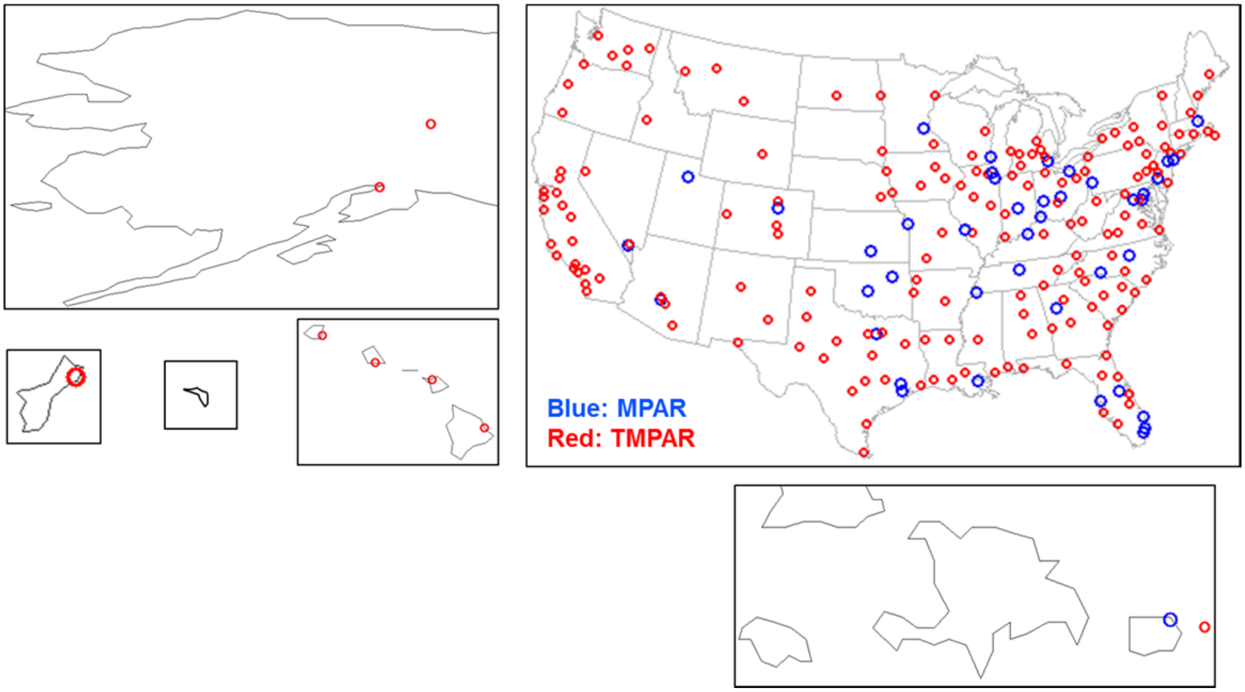

Figure 3-2. Locations of MPAR (blue) and TMPAR (red) for Scenario 1. Clockwise from top left: Alaska, CONUS, Puerto Rico/Virgin Islands/Guantanamo Bay, Hawaii, Kwajalein, and Guam.

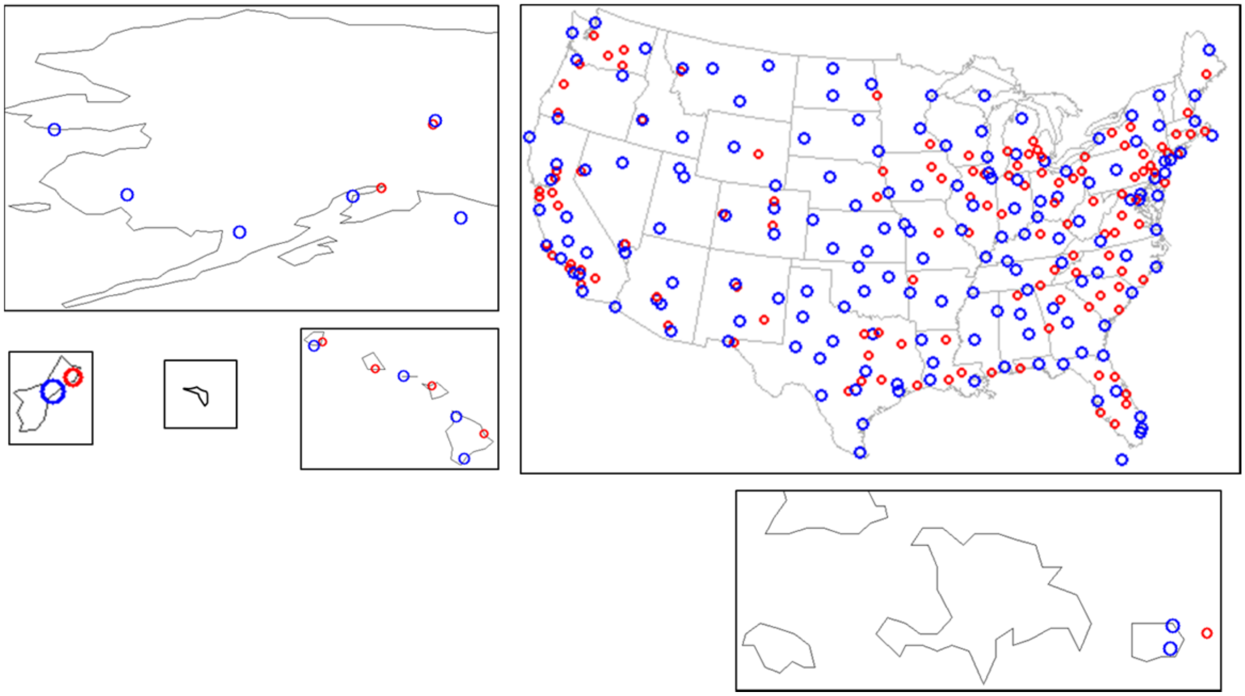

Figure 3-3. Locations of MPAR (blue) and TMPAR (red) for Scenario 2. Clockwise from top left: Alaska, CONUS, Puerto Rico/Virgin Islands/Guantanamo Bay, Hawaii, Kwajalein, and Guam.

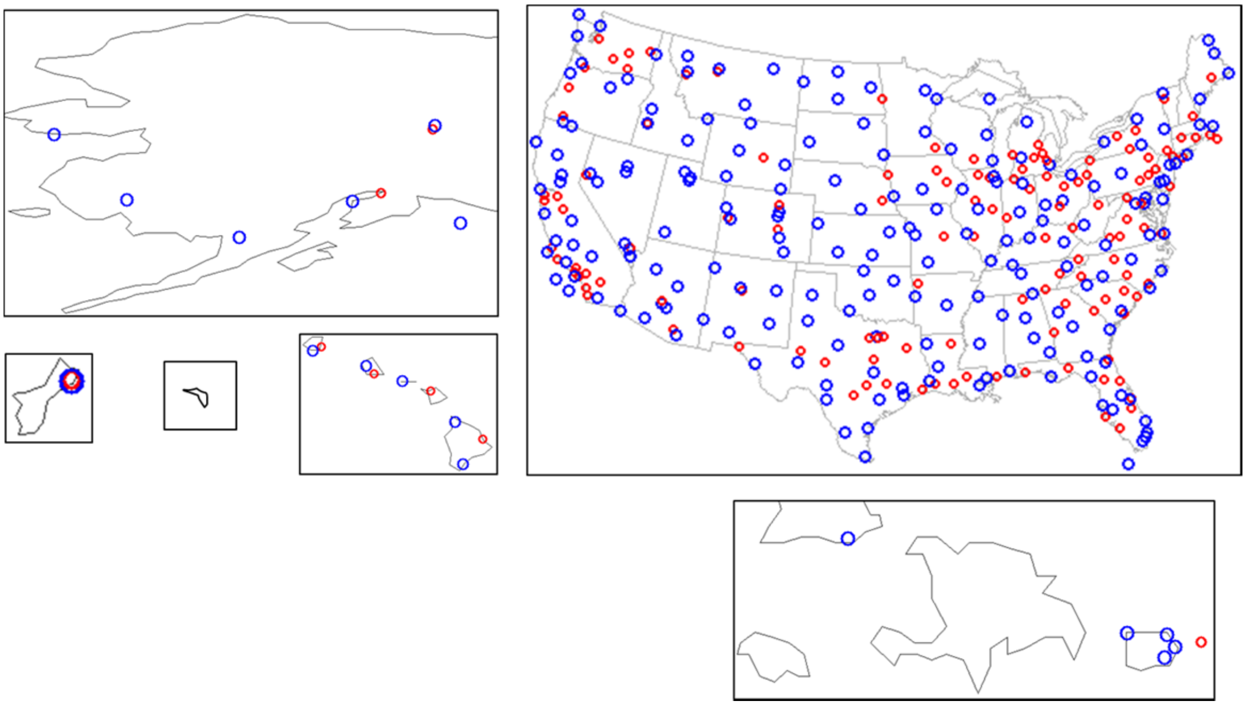

Figure 3-4. Locations of MPAR (blue) and TMPAR (red) for Scenario 3. Clockwise from top left: Alaska, CONUS, Puerto Rico/Virgin Islands/Guantanamo Bay, Hawaii, Kwajalein, and Guam.

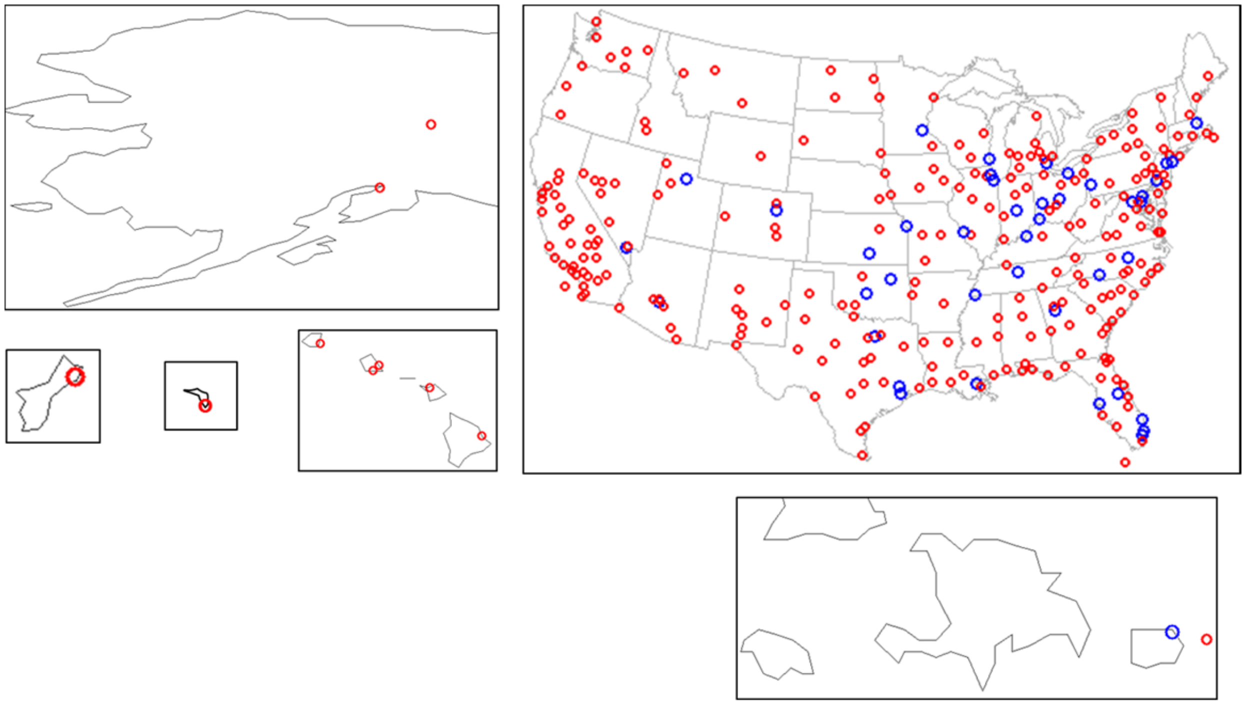

Figure 3-5. Locations of MPAR (blue) and TMPAR (red) for Scenario 1G. Clockwise from top left: Alaska, CONUS, Puerto Rico/Virgin Islands/Guantanamo Bay, Hawaii, Kwajalein, and Guam.

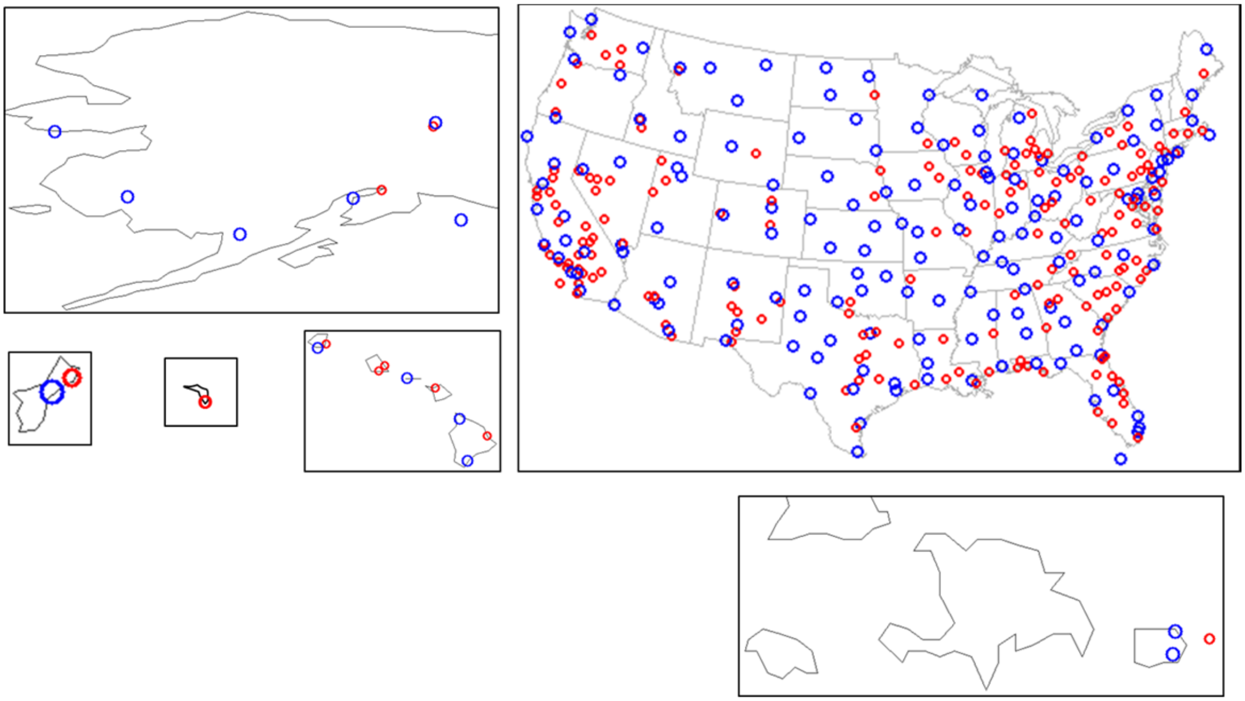

Figure 3-6. Locations of MPAR (blue) and TMPAR (red) for Scenario 2G. Clockwise from top left: Alaska, CONUS, Puerto Rico/Virgin Islands/Guantanamo Bay, Hawaii, Kwajalein, and Guam.

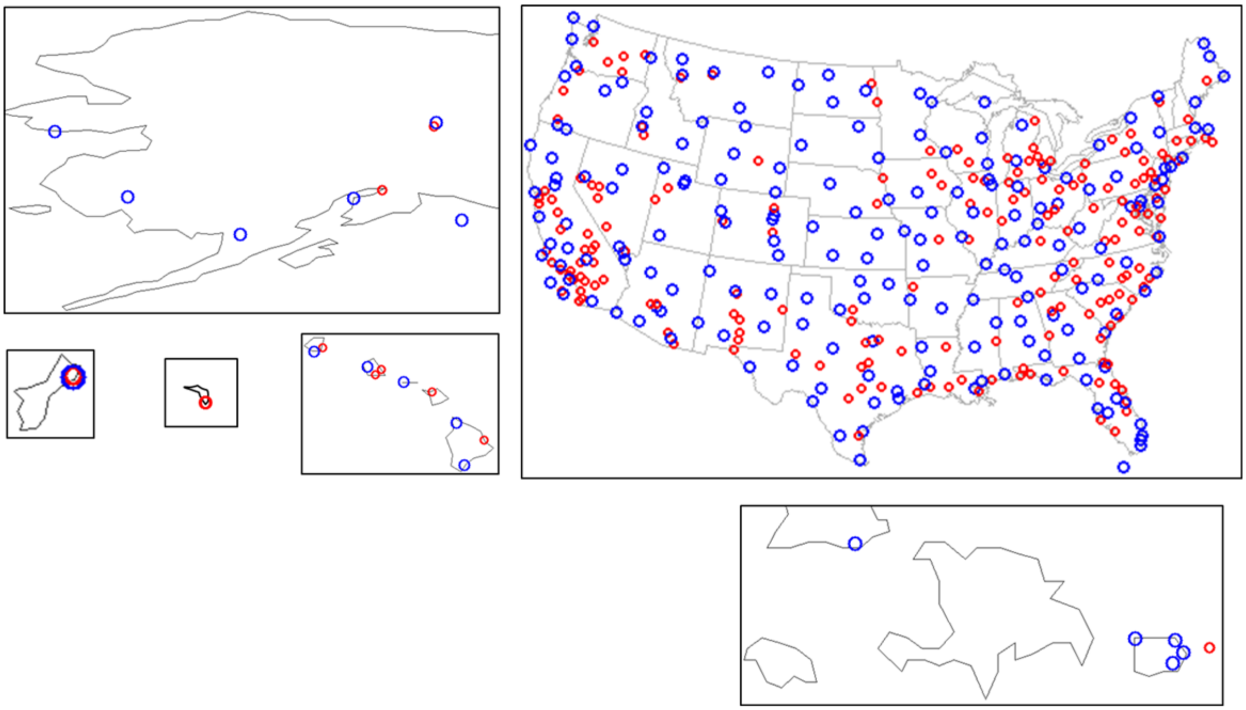

Figure 3-7. Locations of MPAR (blue) and TMPAR (red) for Scenario 3G. Clockwise from top left: Alaska, CONUS, Puerto Rico/Virgin Islands/Guantanamo Bay, Hawaii, Kwajalein, and Guam.

4. STATISTICAL ANALYSIS RESULTS

We now quantify and compare the legacy and MPAR coverages for various parameters. The following parameters were computed: number of Doppler coverage, number of dual-polarization coverage, minimum detectable weather reflectivity, minimum detectable aircraft cross section, and geometric-mean horizontal resolution for weather, vertical resolution for weather, worst-dimension horizontal resolution for aircraft, and vertical accuracy for aircraft.

The number of Doppler coverage is the number of radars with visibility to a coverage grid cell that outputs Doppler weather parameters (radial velocity and spectral width) for this location. This value has a strong influence on how accurately the wind vector is measured at this point. For example, the Integrated Terminal Weather System (ITWS) Terminal Winds product shows dramatic improvement in wind vector accuracy when coverage is provided by two or more Doppler radars (Cho and Martin 2007). Although the ASR-9 WSP generates Doppler data, because its vertical resolution is poor (and, thus, is not suitable for wind vector estimation), we did not include it in this parameter.

The number of dual-polarization coverage is the number of radars that are within range and visibility to a grid cell that yield dual-polarization weather parameters. The primary significance of this value is determined by whether it is zero or greater than zero. (There may be some product quality improvement when there is multiple overlap.) Dual-polarization data yield hydrometeor type differentiation capability (as well as improvement in other estimates such as rainfall rate and icing potential) lacking in single-polarization data.

The minimum detectable weather reflectivity is a measure of the sensitivity of the observing radar. It is based on the reflectivity that would generate a single-pulse signal-to-noise ratio of about unity at the receiver output. The minimum detectable aircraft cross section was estimated for a Swerling 1 target with detection rate of 80% and false alarm probability of 10^{-6}.

The horizontal resolution parallel to and perpendicular to the radar beam are given by

$$\Delta h_{\parallel} = \frac{\Delta r}{r} r_h + \Delta\theta\sqrt{r^2 - r_h^2} \tag{4-1}$$

and

$$\Delta h_{\perp} = r\Delta\phi \ , \tag{4-2}$$

where r is slant range, r_h is horizontal range, Δr is range resolution, $\Delta\phi$ is azimuthal resolution, and $\Delta\theta$ is range from the radar multiplied by the elevation beam width (converted to radians). To distill the asymmetric orthogonal resolution values given by (4-1) and (4-2), we computed the geometric-mean horizontal resolution $(\Delta h_{\parallel}\Delta h_{\perp})^{1/2}$ and the "worst dimension" horizontal resolution (the maximum of $\Delta h_{\parallel}$

and $\Delta h_{\perp}$). Since weather is a diffuse target usually spanning multiple horizontal resolution units, we used the geometric mean parameter to characterize its effective resolution. For aircraft detection, we used the worst dimension metric because it is virtually a point target within the horizontal resolution. Note that we did not attempt to capture the best possible horizontal accuracy estimate for aircraft observation, as this would entail a more complex analysis involving multilateration.

Vertical resolution for weather observation is determined by the range times the elevation angle resolution given in Tables 2-1 and 2-2. For the legacy radars, this parameter is limited by their sparse volume scanning strategies. For aircraft, vertical accuracy is the more relevant parameter, and measurement within a beam width is made possible by angle-of-arrival techniques like monopulse and beam-space maximum likelihood estimation.

4.1 COVERAGE OVER EN ROUTE AIR SPACE

First, we will examine the various performance parameter coverages for horizontal slices at absolute altitudes above mean sea level. All air space considered in this study is included. Table 4-1 gives the results for the 629 legacy radars. Each entry shows how much of the air space satisfies the given column heading condition. Some of the conditional values have clear rationales. Number of Doppler ≥ 2 allows direct wind vector measurement. Weather reflectivity = 18 dBZ is the lower boundary of Level 1 (light or mist) precipitation. And minimum detectable aircraft cross section of 2.2 m^2 (3.4 dBsm) is often used for en route surveillance radar coverage specification. Coverage percentages are over area at each height slice, but are over all valid air space volume for the last row (“All”). Weather observation parameters are shown up to 70,000 ft MSL, which is the coverage ceiling for legacy radars. The ARSR-4 has a mission ceiling of 100,000 ft MSL, so we extend the tables to this height for aircraft surveillance parameters.

TABLE 4-1

Legacy Performance Parameter Coverage Percentage

Height (kft MSL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Min. dBsm <3.4	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	A/C Worst Horiz. Res. ≤1 km	A/C Vert. Acc. ≤500 ft
10	35	67	67	63	64	3	7	3
20	60	88	89	80	50	0.1	4	2
30	68	91	95	82	35	0	3	2
40	68	91	98	83	27	0	2	2
50	68	91	99	83	20	0	1	2
60	68	91	99	83	13	0	0.6	1
70	67	90	99	83	6	0	0.2	0.7
80	N/A	N/A	N/A	58	N/A	N/A	0.01	0.1
90	N/A	N/A	N/A	58	N/A	N/A	0	0
100	N/A	N/A	N/A	58	N/A	N/A	0	0
All	59	84	89	71	31	0.7	2	1

Scenario 2 results are given in Table 4-2. (Scenarios 1 and 1G are not considered in this subsection, because they only cover terminal air space.) As en route aircraft surveillance radars are not replaced in Scenario 2, we focus on the weather observation parameters. The altitude coverage only goes up to 70,000 ft MSL, because Scenario 2 does not include the ARSR-4 mission. The Guantanamo Bay air space is also excluded, because there is only an ARSR-4 there. The last two columns are a way to assess how much the exact coverage spaces diverge between the MPAR and legacy cases. The seventh column shows the percentage of <18 dBZ legacy coverage grid points not covered by MPAR, and the final column shows the percentage for the inverse condition. For these "percentage missed" comparisons, the MPAR coverage is compared to the coverage provided by the legacy radars that they would replace (Figure 4-1). The MPAR coverage replicates the legacy coverage extremely well. Comparison with Table 4-1 shows an improvement in coverage for all weather observation parameters listed.

TABLE 4-2

Scenario 2 Performance Parameter Coverage Percentage

Height (kft MSL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed
10	40	68	68	68	5	0.3	1
20	64	89	89	81	5	0.1	0.4
30	79	96	96	73	4	0.002	0.2
40	85	98	98	64	3	0.003	0.2
50	87	99	99	54	2	0.004	0.3
60	87	99	99	45	2	0.005	0.4
70	87	100	100	37	1	0.005	0.5
All	72	90	90	59	3	0.1	0.8

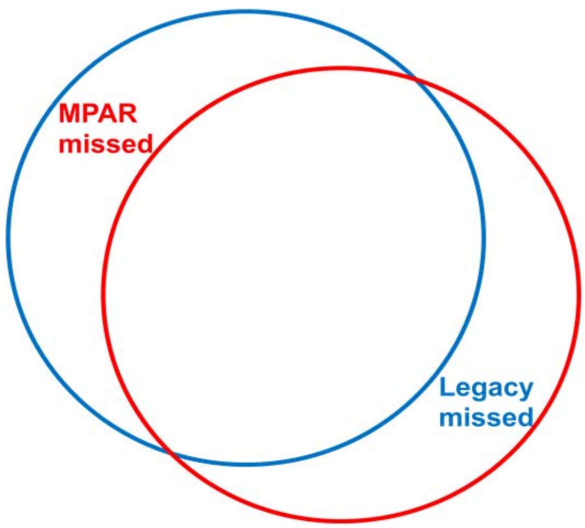

Figure 4-1. Illustration of percentage coverage missed metric. The blue and red circles represent legacy and MPAR coverages, respectively. The legacy missed percentage is computed by dividing the lower right crescent-shape area by the area of the red circle. The MPAR missed percentage is calculated by dividing the upper left crescent-shape area by the area of the blue circle.

Table 4-3 displays the Scenario 3 results. Again, the MPAR coverage generally provides significant improvement over the legacy coverage. Weather observation coverage would increase from 89% to 91% and aircraft surveillance coverage would improve from 71% to 81%. As can be seen from the "coverage legacy missed" columns, the gain is substantial, especially for aircraft surveillance. The sharp decrease in coverage above 70,000 ft is due to the required coverage ceiling for TMPAR being set at that height. The 5% aircraft coverage missed by MPAR at 100,000 ft is an artifact generated by our particular choice of beam broadening (gain loss) with elevation angle that we assumed for MPAR. This could be easily adjusted to eliminate the difference in coverage; it is not a performance limitation imposed by the MPAR itself.

TABLE 4-3

Scenario 3 Performance Parameter Coverage Percentage

Height (kft MSL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Min. dBsm <3.4	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	A/C Worst Horiz. Res. ≤1 km	A/C Vert. Acc. ≤500 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed	<3.4 dBsm Coverage MPAR Missed	<3.4 dBsm Coverage Legacy Missed
10	48	74	74	74	73	6	14	31	0.2	9	0.3	13
20	73	92	92	92	83	5	13	32	0.008	5	0.05	13
30	81	97	97	97	76	5	13	32	0.0001	3	0.03	15
40	85	99	99	99	68	4	12	31	0.0002	3	0.003	16
50	86	99	99	99	59	3	11	30	0.001	3	0.002	16
60	87	100	100	100	51	2	10	29	0.005	3	0.0006	16
70	87	100	100	100	42	1	9	28	0.005	3	0.0003	16
80	N/A	N/A	N/A	64	N/A	N/A	2	6	N/A	N/A	0.3	5
90	N/A	N/A	N/A	59	N/A	N/A	1	5	N/A	N/A	0.5	0.9
100	N/A	N/A	N/A	69	N/A	N/A	1	5	N/A	N/A	5	0.7
All	75	91	91	81	64	4	9	22	0.08	5	0.7	11

In addition to the increase in coverage, the observation performance inside the coverage volume will improve due to the dual-polarization weather measurement and aircraft altitude finding capabilities of MPAR. (In contrast, only the NEXRAD has the former and the ARSR-4 has the latter capability among the legacy radars.) And even though the total radar counts would decrease, overlapping Doppler weather coverage will increase overall, which will benefit echo tops and wind vector determination. Comparing legacy to Scenario 3 over all of the air space considered in this study, overlapping Doppler weather coverage would increase from 59% to 75% and dual-polarization coverage would improve from 84% to 91%.

Scenarios 2G and 3G results are given in Tables 4-4 and 4-5. The overall values are very similar to those of Scenarios 2 and 3, respectively.

TABLE 4-4

Scenario 2G Performance Parameter Coverage Percentage

Height (kft MSL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed
10	41	69	69	69	5	0.4	3
20	65	90	90	81	5	0.2	0.6
30	79	96	96	74	4	0.002	0.2
40	85	98	98	64	3	0.004	0.2
50	87	99	99	55	3	0.004	0.3
60	87	99	99	46	2	0.005	0.4
70	87	100	100	37	1	0.005	0.5
All	73	90	90	60	3	0.2	1

TABLE 4-5

Scenario 3G Performance Parameter Coverage Percentage

Height (kft MSL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Min. dBsm <3.4	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	A/C Worst Horiz. Res. ≤1 km	A/C Vert. Acc. ≤500 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed	<3.4 dBsm Coverage MPAR Missed	<3.4 dBsm Coverage Legacy Missed
10	50	75	75	75	74	6	15	32	0.3	10	0.4	12
20	74	92	92	92	83	6	14	33	0.01	5	0.08	13
30	81	97	97	97	76	5	13	33	0.0001	3	0.03	15
40	85	99	99	99	68	4	12	32	0.0002	3	0.003	16
50	86	99	99	99	60	3	12	31	0.001	3	0.002	16
60	87	100	100	100	51	2	11	30	0.005	3	0.0006	16
70	87	100	100	100	43	1	9	28	0.005	3	0.0003	16
80	N/A	N/A	N/A	64	N/A	N/A	2	5	N/A	N/A	0.6	5
90	N/A	N/A	N/A	59	N/A	N/A	1	5	N/A	N/A	0.8	0.9
100	N/A	N/A	N/A	53	N/A	N/A	1	4	N/A	N/A	6	0.7
All	75	91	91	81	64	4	9	23	0.1	5	0.9	11

We can also analyze coverage at low altitudes using height slices above local ground level. Boundary layer weather observations are crucial for improving weather forecasts (NRC, 2008), while low-altitude aircraft surveillance is important for detecting and tracking rogue flyers. Tables 4-6 to 4-10 give the low-altitude coverage results for the legacy, Scenarios 2, 3, 2G, and 3G cases. As with the high-altitude cases, the low-altitude MPAR coverage improves on the legacy coverage. For weather, the coverage improvement peaks at around 2,500 ft AGL (+7% for Scenario 2, +9% for Scenario 2G, +14% for Scenario 3, +15% for Scenario 3G), and it is reassuring to note that there is no overall loss of overlapping Doppler coverage, which is helpful for wind vector measurements. In Scenarios 3 and 3G, there is a dramatic enhancement in the ability to determine the vertical position of aircraft, which is not surprising, since only the ARSR-4 has this capability among the legacy radars. Finally, the maximum percentage of legacy coverage missed by MPAR for either weather or aircraft surveillance does not exceed 2% at any altitude.

TABLE 4-6

Legacy Low-Altitude Performance Parameter Coverage Percentage

Height (ft AGL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Min. dBsm <3.4	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	A/C Worst Horiz. Res. ≤1 km	A/C Vert. Acc. ≤500 ft
100	0.2	2	3	8	3	2	5	2
200	0.4	3	4	11	4	3	6	2
300	0.6	5	6	14	6	4	7	2
400	0.9	6	7	16	7	4	8	2
500	1	8	9	19	9	5	8	2
1,000	3	15	17	29	16	5	9	2
1,500	5	22	24	37	23	5	9	2
2,000	7	29	30	42	29	5	9	2
2,500	8	34	35	45	35	4	9	2
3,000	10	40	41	49	40	4	9	3
3,500	13	45	46	52	44	4	9	3
4,000	16	50	50	55	48	4	9	3
4,500	20	54	54	58	52	4	8	3
5,000	23	58	58	60	54	4	8	3

TABLE 4-7

Scenario 2 Low-Altitude Performance Parameter Coverage Percentage

Height (ft AGL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed
100	0.2	4	4	4	2	0.6	2.3
200	0.4	6	6	6	3	0.9	3
300	0.6	9	9	9	4	1	4
400	1	11	11	11	4	1	5
500	1	13	13	13	4	1	6
1,000	4	23	23	23	5	2	8
1,500	8	30	30	30	5	1	8
2,000	13	36	36	36	5	1	8
2,500	17	42	42	41	5	1	7
3,000	21	46	46	45	5	0.9	6
3,500	24	50	50	49	5	0.8	5
4,000	28	55	55	53	5	0.7	4
4,500	31	59	59	56	5	0.6	3
5,000	35	62	62	59	5	0.6	2

TABLE 4-8

Scenario 3 Low-Altitude Performance Parameter Coverage Percentage

Height (kft AGL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Min. dBsm <3.4	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	A/C Worst Horiz. Res. ≤1 km	A/C Vert. Acc. ≤500 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed	<3.4 dBsm Coverage MPAR Missed	<3.4 dBsm Coverage Legacy Missed
100	0.4	7	7	7	7	3	5	6	0.6	5	0.7	0.9
200	0.8	10	10	10	10	4	7	8	0.9	7	0.9	1
300	1	12	12	12	12	4	9	10	1	8	1	2
400	2	15	15	15	15	5	10	12	1	9	1	2
500	2	17	17	17	17	5	11	14	1	10	1	3
1,000	6	28	28	28	28	5	13	21	1	14	2	4
1,500	11	37	37	37	37	5	14	26	1	15	2	6
2,000	17	44	44	44	43	6	14	28	1	16	2	8
2,500	21	49	49	49	49	6	14	29	0.9	15	2	9
3,000	26	54	54	54	53	6	15	30	0.7	15	1	9
3,500	30	58	58	58	57	6	15	30	0.6	14	1	10
4,000	34	61	61	61	61	6	15	31	0.5	13	1	10
4,500	38	64	64	64	64	6	15	31	0.4	12	1	10
5,000	41	67	67	67	67	6	15	31	0.3	11	0.9	10

TABLE 4-9

Scenario 2G Low-Altitude Performance Parameter Coverage Percentage

Height (ft AGL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed
100	0.3	5	5	5	3	0.7	3
200	0.6	8	8	8	4	1	4
300	1	10	10	10	4	1	6
400	2	12	12	12	4	1	7
500	2	15	15	15	5	1	7
1,000	6	25	25	25	5	2	10
1,500	11	32	32	32	5	2	10
2,000	16	38	38	38	5	1	10
2,500	20	44	44	43	5	1	9
3,000	24	48	48	47	5	1	8
3,500	27	52	52	51	5	0.9	5
4,000	31	56	56	55	5	0.9	5
4,500	34	60	60	58	5	0.8	4
5,000	38	63	63	60	5	0.8	4

TABLE 4-10

Scenario 3G Low-Altitude Performance Parameter Coverage Percentage

Height (kft AGL)	Doppler ≥2	Dual Pol. ≥1	Min. dBZ <18	Min. dBsm <3.4	Wx Mean Horiz. Res. ≤1 km	Wx Vert. Res. ≤2,000 ft	A/C Worst Horiz. Res. ≤1 km	A/C Vert. Acc. ≤500 ft	<18 dBZ Coverage MPAR Missed	<18 dBZ Coverage Legacy Missed	<3.4 dBsm Coverage MPAR Missed	<3.4 dBsm Coverage Legacy Missed
100	0.5	8	8	8	8	3	6	6	0.7	6	0.8	0.8
200	1	11	11	11	11	4	8	9	1	8	1	1
300	2	14	14	14	13	5	9	11	1	9	1	1
400	2	16	16	16	16	5	11	13	1	10	1	2
500	3	19	19	19	19	5	12	15	1	11	2	2
1,000	8	30	30	30	30	6	14	22	2	15	2	3
1,500	14	38	38	38	38	6	15	26	1	17	2	4
2,000	19	45	45	45	45	6	15	29	1	17	2	6
2,500	24	50	50	50	50	6	15	30	0.8	16	1	8
3,000	28	55	55	55	54	6	15	31	0.7	15	1	8
3,500	33	59	59	59	58	6	15	31	0.7	15	1	8
4,000	36	62	62	62	61	6	15	32	0.6	14	1	9
4,500	40	65	65	65	64	6	15	32	0.6	13	1	9
5,000	43	68	68	68	66	6	15	32	0.5	12	0.9	9

To highlight the increase in boundary layer dual-polarization coverage with MPAR, we plot the legacy and Scenario 3G dual-polarization coverages at 1,000 ft AGL over the CONUS in Figure 4-2. Coverage is doubled from 15% to 30%. Note especially the improvement in highly populated areas.

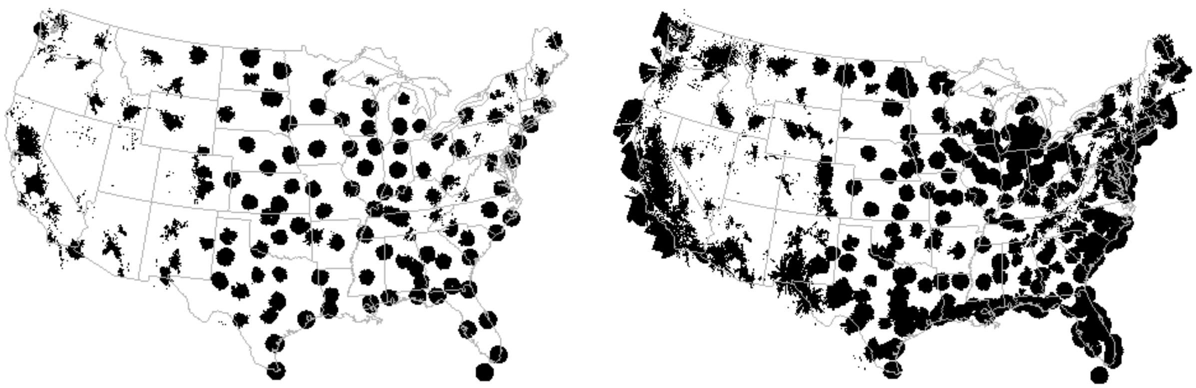

Figure 4-2. CONUS dual-polarization weather coverage at 1,000 ft AGL for (left) legacy and (right) Scenario 3G.

For ease of comparison between the legacy and MPAR cases, we plotted four of the parameters from Tables 4-1, 4-4, and 4-5 in Figure 4-3.

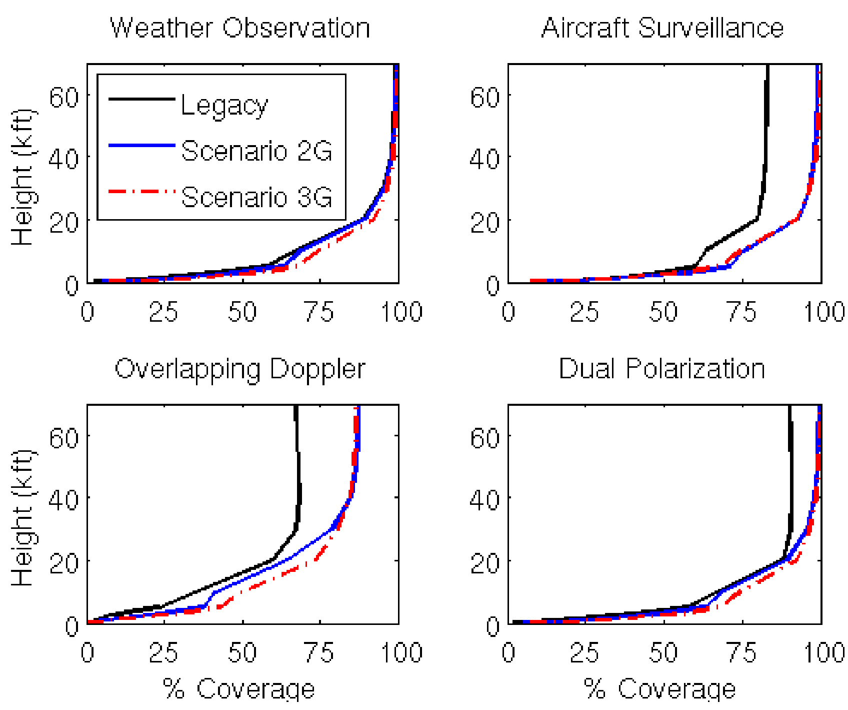

Figure 4-3. Height profiles of coverage percentage for minimum detectable weather reflectivity <18 dBZ (upper left), minimum detectable aircraft cross section <3.4 dBsm (upper right), Doppler weather coverage overlap ≥2 (lower left), and dual-polarization weather coverage (lower right). Heights are MSL above 5,000 ft and AGL otherwise.

4.2 COVERAGE OVER CIVIL TERMINAL AIR SPACE

Landing and take-off are the riskiest phases of flight. Flying more closely to the Earth's surface than during the en route phase, the aircraft has less time to recover after encountering a dangerous weather phenomenon, and there is a higher density of other aircraft from which safe distance must be maintained. Radar surveillance data for both aircraft tracking and hazardous weather detection in terminal air space are crucial for maintaining aviation safety and efficiency. With these points in mind, we compiled terminal air space coverage statistics for primary ASR- and TDWR-associated civil airports in this study. LGA was also added to this list, since it is a super density operations (SDO) airport that relies on the JFK ASR-9 and TDWR. Military airbases/GPN sites were excluded. The overall means are collected in Table 4-11.

TABLE 4-11

Average Terminal Air Space Performance Parameter Coverage Percentage

<table>
<tr><th rowspan="2">Parameter</th><th colspan="4">≤1,500 ft and 6 nmi radius</th><th colspan="4">≤24,000 ft and 60 nmi radius</th></tr>
<tr><th>Legacy</th><th>Sc. 1</th><th>Sc. 2</th><th>Sc. 3</th><th>Legacy</th><th>Sc. 1</th><th>Sc. 2</th><th>Sc. 3</th></tr>
<tr><td>Doppler Coverage ≥1</td><td>47</td><td>93</td><td>93</td><td>93</td><td>84</td><td>91</td><td>90</td><td>92</td></tr>
<tr><td>Doppler Coverage ≥2</td><td>16</td><td>45</td><td>21</td><td>27</td><td>57</td><td>82</td><td>74</td><td>79</td></tr>
<tr><td>Dual Polarization Coverage ≥1</td><td>37</td><td>93</td><td>93</td><td>93</td><td>82</td><td>91</td><td>90</td><td>92</td></tr>
<tr><td>Minimum Detectable Wx Reflectivity <–10|0 dBZ</td><td>41</td><td>50</td><td>53</td><td>52</td><td>81</td><td>83</td><td>82</td><td>85</td></tr>
<tr><td>Minimum Detectable A/C Cross Section ≤0 dBsm</td><td>93</td><td>93</td><td>93</td><td>93</td><td>89</td><td>91</td><td>92</td><td>92</td></tr>
<tr><td>Wx Mean Horizontal Resolution ≤0.25|0.5 km</td><td>27</td><td>83</td><td>84</td><td>83</td><td>26</td><td>37</td><td>51</td><td>54</td></tr>
<tr><td>Wx Vertical Resolution ≤500|1,000 ft</td><td>11</td><td>26</td><td>29</td><td>27</td><td>1</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td>A/C Worst Horizontal Resolution ≤0.25|0.5 km</td><td>57</td><td>64</td><td>70</td><td>68</td><td>5</td><td>8</td><td>10</td><td>10</td></tr>
<tr><td>A/CVertical Accuracy ≤100|200 ft</td><td>0.1</td><td>61</td><td>70</td><td>68</td><td>0.7</td><td>9</td><td>14</td><td>14</td></tr>
<tr><td><–10|0 dBZ Coverage MPAR Missed</td><td>N/A</td><td>2</td><td>4</td><td>5</td><td>N/A</td><td>0.7</td><td>4</td><td>3</td></tr>
<tr><td><–10|0 dBZ Coverage Legacy Missed</td><td>N/A</td><td>14</td><td>17</td><td>17</td><td>N/A</td><td>17</td><td>4</td><td>7</td></tr>
<tr><td>≤0 dBsm Coverage MPAR Missed</td><td>N/A</td><td>0.1</td><td>0.1</td><td>0.2</td><td>N/A</td><td>0.1</td><td>0.09</td><td>0.6</td></tr>
<tr><td>≤0 dBsm Coverage Legacy Missed</td><td>N/A</td><td>0.3</td><td>0.8</td><td>0.6</td><td>N/A</td><td>9</td><td>12</td><td>3</td></tr>
</table>

Statistics were compiled over two subvolumes within the terminal air space: (1) altitude ≤ 1,500 ft AGL and range ≤ 6 nmi from the airport, and (2) altitude ≤ 24,000 ft AGL and range ≤ 60 nmi from the airport. These subvolumes correspond to the required coverage volume for hazardous wind-shear detection (FAA, 1995) and terminal aircraft surveillance (Raytheon, 1999). Different performance parameter thresholds were used for the two subvolumes as indicated in Table 4-7 (divided by a "|"). Note that this table is different from the en route coverage tables in that coverages were averaged over altitude and range instead of slices taken at individual heights.

Once again, overall coverage and performance figures are better for the MPAR compared to legacy radars. The vast improvement in aircraft vertical position accuracy occurs because the legacy ASRs do not provide this capability at all. (The very small fractions that show up under the legacy column for this parameter is due to a bit of ARSR-4 coverage that extends into some terminal air space.)

For the given thresholds, the MPAR provides a faithful replication of the legacy terminal air space coverage, especially for aircraft surveillance. The somewhat larger "miss" percentages (up to 5%) for weather observation is due to our methodology of locating terminal MPARs on the airport rather than at the stand-off TDWR sites. Much of this difference can be made up in the 60-nmi-radius case if the assumed instrumented range for the TMPAR is increased beyond 90 km. Technically, there is no reason not to do so. In fact, the Doppler weather parameter coverage range for today's TDWR could be increased at least twofold with known signal transmission and processing techniques (Cho, 2010).

One may wonder why the weather Doppler coverage redundancy is better in Scenario 1 than in Scenario 2. This is because in Scenario 1 the terminal radar coverage was replaced by MPAR and TMPAR without eliminating any existing NEXRADs; in Scenario 2, the terminal and en route weather coverages were considered together to eliminate unneeded NEXRAD sites. Therefore, Scenario 1 contains more weather coverage redundancy than Scenario 2. This extra redundancy cannot be eliminated in Scenario 1, because NEXRAD is a legacy radar that is not used multifunctionally (at least not to the extent of an MPAR).

Assuming that MPAR will have dual-polarization capability, there will be a big improvement in coverage for this parameter over the legacy case near the airport. If hydrometeor classification and icing condition detection are to be requirements for future terminal air space weather observation under NextGen (FAA, 2009), then dual polarization coverage will be a key component.

Of the 215 civil airports included in this section, 46 are served by TDWRs, 34 have WSPs, and 40 have only LLWASs (see Figure 4-4 for CONUS locations). This leaves 95 airports with no dedicated wind-shear detection systems at this time. (Some of these have or will have NEXRAD gust front and microburst products available to them.) But with the deployment of MPAR, all of them will be provided with excellent wind-shear detection capability. If the 81 military airbase sites are included in the replacement plan, they will also gain wind-shear protection coverage.

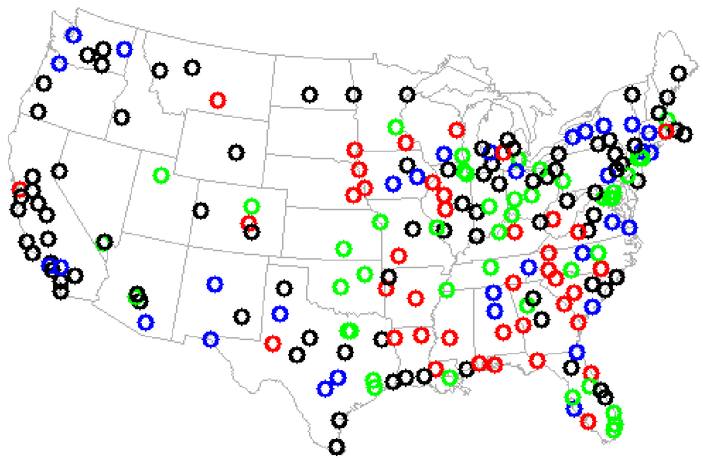

Figure 4-4. CONUS map of the civil airports included in this study. Airports served by TDWR are green, airports with WSP are blue, airports with LLWAS only are red, and those without a dedicated wind-shear detection system are black.

4.3 COVERAGE OVER URBAN AREAS

Beyond aviation purposes for which the FAA is primarily concerned, weather and aircraft surveillance data impact the lives of people on the ground through improved hazardous weather forecasts and protection from rogue air vehicle attacks. Urban areas with their high concentration of people have disproportionate value in coverage by these radars. Thus, we wish to characterize the changes in radar coverage specifically over these regions.

We obtained projected 2010 digital U.S. population density data with 2.5 arc-minute spatial resolution from CIESIN (2005) (Figure 4-5). The U.S. Census Bureau defines an urban area as "Core census block groups or blocks that have a population density of at least 1,000 people per square mile (386 per square kilometer) and surrounding census blocks that have an overall density of at least 500 people per square mile (193 per square kilometer)." Thus, we selected 193/km^2 as the minimum threshold for population density and computed the CONUS urban region legacy and MPAR coverage statistics in Tables 4-12 to 4-18. (Urban region defined in this way is 3.5% of the CONUS area and encompasses 210 million people.) The "legacy" coverage here includes the GPN sites. Low altitudes were emphasized to cover rapid-onset threats to people on the ground such as tornadoes. The threshold for minimum detectable aircraft cross section was also reduced to 0.1 m^2 (–10 dBsm) to make allowance for small targets.

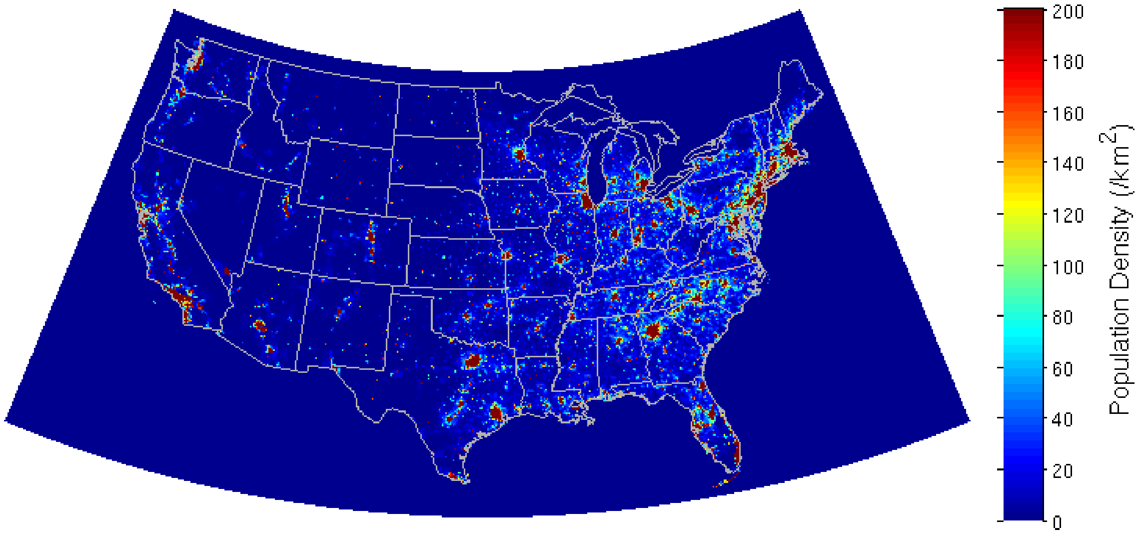

Figure 4-5. CONUS population density map.

TABLE 4-12

Legacy Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	500	1,000	5,000
Doppler Coverage	≥2 radars	1	17	33	70
Dual Polarization Coverage	≥1 radar	5	28	49	97
Minimum Detectable Weather Reflectivity	≤18 dBZ	10	45	63	97
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	30	72	84	96
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	10	45	59	63
Vertical Resolution for Weather	≤1,000 ft	9	24	18	5
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	21	35	37	32
Vertical Accuracy for Aircraft	≤200 ft	2	2	2	2

TABLE 4-13

Scenario 1 Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	**500**	**1,000**	**5,000**
Doppler Coverage	≥2 radars	4	33	59	95
Dual Polarization Coverage	≥1 radar	26	72	88	99
Minimum Detectable Weather Reflectivity	≤18 dBZ	26	72	88	99
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	28	72	87	97
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	26	71	83	83
Vertical Resolution for Weather	≤1,000 ft	13	22	22	19
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	21	41	42	41
Vertical Accuracy for Aircraft	≤200 ft	21	45	47	47

TABLE 4-14

Scenario 2 Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	**500**	**1,000**	**5,000**
Doppler Coverage	≥2 radars	1	15	35	86
Dual Polarization Coverage	≥1 radar	24	69	87	99
Minimum Detectable Weather Reflectivity	≤18 dBZ	24	69	87	99
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	29	74	89	99
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	24	68	84	89
Vertical Resolution for Weather	≤1,000 ft	13	21	22	20
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	22	44	45	43
Vertical Accuracy for Aircraft	≤200 ft	22	49	53	54

TABLE 4-15

Scenario 3 Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	500	1,000	5,000
Doppler Coverage	≥2 radars	2	19	40	89
Dual Polarization Coverage	≥1 radar	27	72	89	99
Minimum Detectable Weather Reflectivity	≤18 dBZ	27	72	89	99
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	27	72	88	99
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	27	71	86	89
Vertical Resolution for Weather	≤1,000 ft	13	21	21	20
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	22	43	45	44
Vertical Accuracy for Aircraft	≤200 ft	23	49	52	53

TABLE 4-16

Scenario 1G Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	500	1,000	5,000
Doppler Coverage	≥2 radars	4	37	64	96
Dual Polarization Coverage	≥1 radar	29	75	89	99
Minimum Detectable Weather Reflectivity	≤18 dBZ	29	75	89	99
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	31	76	89	98
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	28	74	85	85
Vertical Resolution for Weather	≤1,000 ft	14	23	24	20
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	23	43	45	43
Vertical Accuracy for Aircraft	≤200 ft	24	47	50	50

TABLE 4-17

Scenario 2G Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	500	1,000	5,000
Doppler Coverage	≥2 radars	1	20	43	89
Dual Polarization Coverage	≥1 radar	27	73	89	99
Minimum Detectable Weather Reflectivity	≤18 dBZ	27	73	89	99
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	31	76	90	99
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	27	72	85	89
Vertical Resolution for Weather	≤1,000 ft	14	22	23	21
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	24	46	48	45
Vertical Accuracy for Aircraft	≤200 ft	24	52	55	56

TABLE 4-18

Scenario 3G Urban Area Coverage Percentage vs. Height

Parameter	Threshold	Height AGL (ft)			
		100	500	1,000	5,000
Doppler Coverage	≥2 radars	2	23	46	91
Dual Polarization Coverage	≥1 radar	29	75	90	99
Minimum Detectable Weather Reflectivity	≤18 dBZ	29	75	90	99
Minimum Detectable Aircraft Cross Section	≤–10 dBsm	29	75	89	99
Horizontal Resolution for Weather (Dimensional Mean)	≤0.5 km	29	74	87	90
Vertical Resolution for Weather	≤1,000 ft	14	22	23	21
Horizontal Resolution for Aircraft (Worst Dimension)	≤0.5 km	24	46	48	46
Vertical Accuracy for Aircraft	≤200 ft	24	52	55	56

MPAR networks generally improve urban coverage over the legacy network for all parameters and scenarios. The most dramatic enhancements are seen in dual polarization coverage and vertical accuracy of aircraft detection. The former occurs because the only legacy radar with dual polarization is the NEXRAD, whereas all MPARs and TMPARs are assumed to have dual polarization. The better boundary layer coverage with dual polarization will allow more accurate characterization of hydrometeor type and provide valuable data for assimilation into numerical weather forecast models. Finer vertical accuracy for aircraft detection results because the only legacy radar with this capability is the ARSR-4, whereas all MPARs and TMPARs will be able to measure the altitude of aircraft. This parameter will be crucial in tracking uncooperative air targets or when the Automatic Dependent Surveillance-Broadcast (ADS-B) relayed positional data are not available due to Global Position System (GPS) jamming, severe geomagnetic storms, etc.

5. CONCLUSIONS

The main purpose of this study was to determine, to first order, the number of MPARs and TMPARs needed to replicate the weather and aircraft surveillance coverage provided by existing radars for six replacement scenarios: (1) terminal radars only (ASRs and TDWRs), (2) terminal radars and national-scale weather radars (ASRs, TDWRs, and NEXRADs), and (3) terminal radars, national-scale weather radars, and long-range aircraft surveillance radars (ASRs, TDWRs, NEXRADs, CARSRs, and ARSR-4s); scenarios 1G, 2G, and 3G added military airbase radars to the first three replacement scenarios. The locations and tower heights for the new radars were restricted to those of the existing radars. In reality, a transition period would require the legacy and replacement radars to be simultaneously operating, which would necessitate different locations and towers for the new radars. Therefore, the MPAR locations given in this report should only be used as a guide for future, more locally detailed, analyses that would provide the final siting data. With that caveat in mind, we conclude the following.

Replacing the legacy radars by MPARs and TMPARs would reduce the total number of radars by 18%/14% (Scenarios 1/1G), 29%/28% (Scenarios 2/2G), and 35%/35% (Scenarios 3/3G). Despite the reduction in radar count, coverage volume for weather and aircraft surveillance would increase modestly. Dual-polarization and overlapping Doppler weather coverage will improve.

Terminal aircraft surveillance coverage would be strictly preserved under this MPAR siting scheme. Airports currently equipped with an ASR but no wind-shear observation system would gain wind-shear detection coverage through a TMPAR or MPAR. Airports currently equipped with an ASR but without a nearby NEXRAD would get high-quality dual-polarization Doppler weather data. On average, terminal air spaces will have more overlapping Doppler weather coverage, increased dual-polarization weather radar data, and gain the capability for aircraft altitude estimation.

Finally, low-altitude urban airspace coverage will be improved with MPAR for all replacement scenarios. More overlapping Doppler weather radar coverage, better spatial resolution for weather and aircraft surveillance, and, most of all, enhancements in dual-polarization coverage and vertical accuracy of aircraft detection will be obtained compared to the legacy radar network.

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APPENDIX A: SITE-BY-SITE LISTING OF PROPOSED RADAR DEPLOYMENT

For each relevant scenario, the tables below list the site-by-site radar replacement proposal—MPAR, TMPAR, or none. If fewer than four antenna faces are specified, this is indicated by the number of faces and azimuth coverage range in parentheses. In the ASR table, site IDs currently with WSPs are marked with asterisks. For the GPN sites, the radar ownership is indicated as AF = Air Force, AR = Army, MC = Marine Corps, N = Navy, and NG = National Guard.

TABLE A-1

ASR Sites

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
ABE	ALLENTOWN	PA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ABI	ABILENE	TX	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
ABQ*	ALBUQUERQUE	NM	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ACK	NANTUCKET	MA	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
ACT	WACO	TX	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ACY	ATLANTIC CITY	NJ	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ADW	ANDREWS AFB (CAMP SPRINGS)	MD	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
AGS	AUGUSTA	GA	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ALB*	ALBANY	NY	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
ALO	WATERLOO	IA	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
AMA	AMARILLO	TX	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
ANC	ANCHORAGE #1	AK	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ANC2	ANCHORAGE #2	AK	ASR-11	None	None	None	None	None	None
ATL	ATLANTA	GA	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
AUS*	AUSTIN	TX	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
AVL	ASHEVILLE	NC	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
AVP	WILKES BARRE	PA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
AZO	KALAMAZOO	MI	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BAB	MARYSVILLE (BEALE AFB)	CA	ASR-9	TMPAR	TMPAR	MPAR (3: 220°–130°)	TMPAR	TMPAR	MPAR (3: 220°–130°)
BAD	SHREVEPORT (BARKSDALE AFB)	LA	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BDL*	WINDSOR LOCKS	CT	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BFL	BAKERSFIELD	CA	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BGM	BINGHAMTON	NY	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BGR	BANGOR	ME	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BHM*	BIRMINGHAM	AL	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BIL	BILLINGS	MT	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BIS	BISMARK	ND	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BLV	SCOTT AFB (BELLEVILLE)	IL	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BNA	NASHVILLE	TN	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
BNH	BRENHAM	TX	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BOI	BOISE	ID	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BOS	BOSTON	MA	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
BPT	BEAUMONT	TX	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BTR	BATON ROUGE	LA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BTV	BURLINGTON	VT	ASR-11	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
BUF*	BUFFALO	NY	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
BUR	BURBANK	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
BWI	BALTIMORE	MD	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
CAE	COLUMBIA	SC	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CAK	AKRON/CANTON	OH	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CHA	CHATTANOOGA	TN	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
CHO	CHARLOTTESVILLE	VA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CHS*	CHARLESTON	SC	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CID*	CEDAR RAPIDS	IA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CKB	CLARKSBURG	WV	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CLEA	CLEVELAND	OH	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
CLT	CHARLOTTE	NC	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
CMH	COLUMBUS	OH	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
CMI	CHAMPAIGN	IL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
COS	COLORADO SPRINGS	CO	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
COU	COLUMBIA	MO	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CPR	CASPER	WY	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CRP	CORPUS CHRISTI	TX	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
CRW	CHARLESTON	WV	ASR-8	TMPAR	MPAR	MPAR (3: 315°–225°)	TMPAR	MPAR	MPAR (3: 315°–225°)
CSG	COLUMBUS	GA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
CUM	CUMBERLAND (PORTLAND)	ME	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
CVG	COVINGTON (CINCINNATI)	KY	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
DAB	DAYTONA BEACH	FL	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
DAY	DAYTON	OH	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
DCA	WASHINGTON NATIONAL	VA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
DENA	DENVER #1 (IRONDALE)	CO	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
DFW	DALLAS FT WORTH #4 (WEST)	TX	ASR-9	None	None	None	None	None	None
DFWA	DALLAS FT WORTH #1 (EAST)	TX	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
DLH	DULUTH	MN	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
DPA	DUPAGE (ORD #4, WEST)	IL	ASR-9	TMPAR (2: 180°–360°)	TMPAR (2: 180°–360°)	TMPAR (2: 180°–360°)	TMPAR (2: 180°–360°)	TMPAR (2: 180°–360°)	TMPAR (2: 180°–360°)
DSM*	DES MOINES	IA	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
DTWA	DETROIT #1 (ROMULUS)	MI	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
DTWC	PONTIAC (DTW #2, NORTHVILLE)	MI	ASR-9	TMPAR (2: 225°–45°)	TMPAR (2: 225°-45°)	TMPAR (2: 225°–45°)	TMPAR (2: 225°–45°)	TMPAR (2: 225°–45°)	TMPAR (2: 225°–45°)
ELM	ELMIRA	NY	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ELP*	EL PASO (BIGGS AFB)	TX	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ERI	ERIE	PA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
EUG	EUGENE	OR	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
EVV	EVANSVILLE	IN	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
EWR	NEWARK	NJ	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
FAI	FAIRBANKS	AK	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FAR	FARGO	ND	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FAT	FRESNO	CA	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
FAY	FAYETTEVILLE	NC	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FLL	FT LAUDERDALE	FL	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
FLO	FLORENCE	SC	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FMH	FALMOUTH (OTIS AFB)	MA	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FNT	FLINT	MI	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FSD	SIOUX FALLS	SD	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
FSM	FT SMITH	AR	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
FWA	FT WAYNE	IN	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
FYV	FAYETTEVILLE	AR	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
GEG*	SPOKANE	WA	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
GGG	LONGVIEW (TYLER)	TX	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
GNV	GAINESVILLE	FL	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
GPT	GULFPORT	MS	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
GRB	GREEN BAY	WI	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
GRR*	GRAND RAPIDS	MI	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
GSO*	GREENSBORO	NC	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
GSP	GREER (GREENVILLE)	SC	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
GTF	GREAT FALLS	MT	ASR-8	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
GXY	PLATTEVILLE (DEN #2)	CO	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
HNL*	HONOLULU	HI	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
HOUA	HOUSTON (HOBBY)	TX	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
HPN*	WHITE PLAINS	NY	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
HRL	HARLINGEN (BROWNSVILLE)	TX	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
HSV*	HUNTSVILLE	AL	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
HTS	HUNTINGTON	WV	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
HUF	TERRA HAUTE	IN	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
IAD	CHANTILLY (DULLES)	VA	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
IAH	HOUSTON (INTERNATIONAL)	TX	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
ICT	WICHITA	KS	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
ILM	WILMINGTON	NC	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
IND	INDIANAPOLIS	IN	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
ISP*	ISLIP	NY	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ITO	HILO	HI	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
IWA	PHOENIX-GATEWAY (WILLIAMS AFB)	AZ	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
JAN	JACKSON	MS	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
JAX*	JACKSONVILLE	FL	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
JFK	NEW YORK	NY	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
LAN	LANSING	MI	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LAS	LAS VEGAS	NV	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
LAXN	LOS ANGELES (NORTH)	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LAXS*	LOS ANGELES (SOUTH)	CA	ASR-9	None	None	None	None	None	None
LBB*	LUBBOCK (REESE AFB)	TX	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
LCH	LAKE CHARLES	LA	ASR-8	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
LEX	LEXINGTON	KY	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LFT	LAFAYETTE	LA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LGB	LONG BEACH (GARDEN GROVE)	CA	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
LIH	LIHUE	HI	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LIT	LITTLE ROCK	AR	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
LNK	LINCOLN	NE	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LSV	NELLIS AFB	NV	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LYH	LYNCHBURG	VA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
LZU	LAWRENCEVILLE	GA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MAF	MIDLAND	TX	ASR-11	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
MBS	SAGINAW	MI	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MCC	MCCLELLAN AFB (SACRAMENTO)	CA	ASR-9	TMPAR	TMPAR	MPAR	TMPAR	TMPAR	MPAR
MCE	CASTLE AFB (MERCED)	CA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MCI	KANSAS CITY	MO	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
MCN	WARNER ROBINS AFB (MACON)	GA	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
MCO	ORLANDO	FL	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
MDT*	HARRISBURG	PA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MEM	MEMPHIS	TN	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
MFD	MANSFIELD	OH	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MFR	MEDFORD	OR	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MHT	MANCHESTER (HEATON)	NH	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MI2	SACHSE (DFW #3)	TX	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MIA	MIAMI	FL	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
MKE	MILWAUKEE	WI	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
MKG	MUSKEGON	MI	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MLB	PATRICK AFB	FL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MLI	MOLINE	IL	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
MLU	MONROE	LA	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MOB	MOBILE	AL	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
MRB	MARTINSBURG	WV	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MRY	MONTEREY (FT ORD)	CA	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
MSN*	MADISON	WI	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MSO	MISSOULA	MT	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MSP	MINNEAPOLIS	MN	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
MSY	NEW ORLEANS	LA	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
MWH	MOSES LAKE	WA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
MXF	MAXWELL AFB (MONTGOMERY)	AL	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
MYR	MYRTLE BEACH	SC	ASR-11	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
NFG	CAMP PENDLETON (OCEANSIDE)	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
NKX	MIRAMAR MCAS (SAN DIEGO)	CA	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
NUQ	MOFFETT NAS (SAN JOSE)	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
NXX	WILLOW GROVE NAS	PA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
OAK	OAKLAND	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
OFF	OFFUTT AFB (OMAHA)	NE	ASR-9	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
OGG	KAHULUI	HI	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
OKC	OKLAHOMA CITY	OK	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
ONT*	ONTARIO (MARCH AFB)	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ORD	CHICAGO (OHARE) #1	IL	ASR-9	None	None	None	None	None	None
ORD2	CHICAGO (OHARE) #2	IL	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
ORF*	NORFOLK	VA	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
PA2	AZLE (DFW #2)	TX	ASR-9	TMPAR (3: 135°–45°)	TMPAR (3: 135°–45°)	TMPAR (3: 135°–45°)	None	None	None
PBI	WEST PALM BEACH	FL	ASR-11	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
PDX*	PORTLAND	OR	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
PHL	PHILADELPHIA	PA	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
PHX	PHOENIX	AZ	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
PIA	PEORIA	IL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
PIT	PITTSBURGH	PA	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
PNS	PENSACOLA	FL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
PSC	PASCO	WA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
PSP	PALM SPRINGS	CA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
PUB	PUEBLO	CO	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
PVD	COVENTRY (PROVIDENCE)	RI	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
QLO	ORCHARD MESA (GRAND JUNCTION)	CO	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
QXM	TINLEY PARK (ORD #2)	IL	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
RDG	READING	PA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
RDU	RALEIGH-DURHAM	NC	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
RFD	ROCKFORD	IL	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
RIC*	RICHMOND	VA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
RNO	RENO	NV	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ROA	ROANOKE	VA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ROC*	ROCHESTER	NY	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
ROW	ROSWELL	NM	ASR-9	TMPAR	TMPAR	MPAR	TMPAR	TMPAR	MPAR
RST	ROCHESTER	MN	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
RSW	FORT MEYERS	FL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SATA*	SAN ANTONIO	TX	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SAV	SAVANNAH	GA	ASR-8	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
SBA	SANTA BARBARA	CA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SBN	SOUTH BEND	IN	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SCK	STOCKTON	CA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SDF	LOUISVILLE	KY	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
SDL	NORTH VALLEY	AZ	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SEA*	SEATTLE	WA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SGF	SPRINGFIELD	MO	ASR-11	TMPAR	MPAR	MPAR	TMPAR	MPAR	MPAR
SJT	SAN ANGELO	TX	ASR-9	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
SJU	SAN JUAN	PR	ASR-8	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
SLC	SALT LAKE CITY	UT	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
SMX	SANTA MARIA	CA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SPI	SPRINGFIELD	IL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SRQ*	SARASOTA	FL	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
STL	ST LOUIS	MO	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
STT	ST THOMAS	VI	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SUX	SIOUX CITY	IA	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
SWF	NEWBURGH STEWART	NY	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
SYR*	SYRACUSE	NY	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
TLH	TALLAHASSEE	FL	ASR-8	TMPAR	MPAR	TMPAR	TMPAR	MPAR	TMPAR
TOL*	TOLEDO	OH	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
TPA	TAMPA	FL	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
TRI	TRI CITY (BRISTOL)	TN	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
TUL	TULSA	OK	ASR-9	MPAR	MPAR	MPAR	MPAR	MPAR	MPAR
TUS*	TUCSON (DAVIS AFB)	AZ	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
TYS*	KNOXVILLE	TN	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
UAM	ANDERSEN AFB	GU	ASR-8	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
VRB	VERO BEACH	FL	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
YKM	YAKIMA	WA	ASR-9	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR
YNG	YOUNGSTOWN	OH	ASR-11	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR	TMPAR

TABLE A-2

TDWR Sites

Site ID	Site Name	State	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
ADW	ANDREWS AFB	MD	None	None	None	None	None	None
ATL	ATLANTA	GA	None	None	None	None	None	None
BNA	NASHEVILLE	TN	None	None	None	None	None	None
BOS	BOSTON	MA	None	None	None	None	None	None
BWI	BALTIMORE	MD	None	None	None	None	None	None
CLE	CLEVELAND	OH	None	None	None	None	None	None
CLT	CHARLOTTE	NC	None	None	None	None	None	None
CMH	COLUMBUS	OH	None	None	None	None	None	None
CVG	CINCINNATI	OH	None	None	None	None	None	None
DAL	DALLAS (LOVE)	TX	None	None	None	None	None	None

Site ID	Site Name	State	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
DAY	DAYTON	OH	None	None	None	None	None	None
DCA	WASHINGTON (NATIONAL)	DC	None	None	None	None	None	None
DEN	DENVER	CO	None	None	None	None	None	None
DFW	DALLAS-FT WORTH	TX	None	None	None	None	None	None
DTW	DETROIT	MI	None	None	None	None	None	None
EWR	NEWARK	NJ	None	None	None	None	None	None
FLL	FT LAUDERDALE	FL	None	None	None	None	None	None
HOU	HOUSTON (HOBBY)	TX	None	None	None	None	None	None
IAD	WASHINGTON (DULLES)	VA	None	None	None	None	None	None
IAH	HOUSTON (INTERNATIONAL)	TX	None	None	None	None	None	None
ICT	WICHITA	KS	None	None	None	None	None	None
IND	INDIANA	IN	None	None	None	None	None	None
JFK	NEW YORK (KENNEDY)	NY	None	None	None	None	None	None
LAS	LAS VEGAS	NV	None	None	None	None	None	None
MCI	KANSAS CITY	MO	None	None	None	None	None	None
MCO	ORLANDO	FL	None	None	None	None	None	None
MDW	CHICAGO (MIDWAY)	IL	None	None	None	None	None	None
MEM	MEMPHIS	TN	None	None	None	None	None	None
MIA	MIAMI	FL	None	None	None	None	None	None
MKE	MILWAUKEE	WI	None	None	None	None	None	None
MSP	MINNEAPOLIS-ST PAUL	MN	None	None	None	None	None	None
MSY	NEW ORLEANS	LA	None	None	None	None	None	None
OKC	OKLAHOMA CITY	OK	None	None	None	None	None	None
ORD	CHICAGO (OHARE)	IL	None	None	None	None	None	None
PBI	PALM BEACH	FL	None	None	None	None	None	None
PHL	PHILADELPHIA	PA	None	None	None	None	None	None
PHX	PHOENIX	AZ	None	None	None	None	None	None

Site ID	Site Name	State	Scenario 1	Scenario 2	Scenario 3	Scenario 1G	Scenario 2G	Scenario 3G
PIT	PITTSBURGH	PA	None	None	None	None	None	None
RDU	RALEIGH-DURHAM	NC	None	None	None	None	None	None
SDF	LOUISVILLE	KY	None	None	None	None	None	None
SJU	SAN JUAN	PR	None	None	None	None	None	None
SLC	SALT LAKE CITY	UT	None	None	None	None	None	None
STL	ST LOUIS	MO	None	None	None	None	None	None
TPA	TAMPA	FL	None	None	None	None	None	None
TUL	TULSA	OK	None	None	None	None	None	None

TABLE A-3
NEXRAD Sites

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KABR	ABERDEEN	SD	MPAR	MPAR	MPAR	MPAR
KABX	ALBUQUERQUE	NM	MPAR	MPAR	MPAR	MPAR
KAKQ	NORFOLK	VA	None	MPAR (2: 150°–330°)	None	None
KAMA	AMARILLO	TX	None	None	None	None
KAMX	MIAMI	FL	None	None	None	None
KAPX	NCL MICHIGAN	MI	MPAR	MPAR	MPAR	MPAR
KARX	LA CROSSE	WI	MPAR	MPAR	MPAR	MPAR
KATX	SEATTLE	WA	MPAR	MPAR	None	None
KBBX	BEALE AFB	CA	MPAR	None	MPAR	None
KBGM	BINGHAMTON	NY	None	None	None	None
KBHX	EUREKA (BUNKER HILL)	CA	MPAR	None	MPAR	None
KBIS	BISMARCK	ND	None	None	None	None
KBLX	BILLINGS	MT	None	None	None	None
KBMX	BIRMINGHAM	AL	None	None	None	None

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KBOX	BOSTON	MA	None	None	None	None
KBRO	BROWNSVILLE	TX	None	None	None	None
KBUF	BUFFALO	NY	None	None	None	None
KBYX	KEY WEST	FL	MPAR	None	None	None
KCAE	COLUMBIA	SC	None	None	None	None
KCBW	CARIBOU	ME	MPAR	MPAR (3: 30°–300°)	MPAR	MPAR
KCBX	BOISE	ID	MPAR	MPAR	MPAR	MPAR
KCCX	STATE COLLEGE	PA	MPAR	MPAR	MPAR	MPAR
KCLE	CLEVELAND	OH	None	None	None	None
KCLX	CHARLESTON	SC	None	None	None	None
KCRP	CORPUS CHRISTI	TX	None	None	None	None
KCXX	BURLINGTON	VT	None	None	None	None
KCYS	CHEYENNE	WY	MPAR	MPAR	MPAR	MPAR
KDAX	SACRAMENTO	CA	MPAR	None	None	None
KDDC	DODGE CITY	KS	MPAR	MPAR	MPAR	MPAR
KDFX	LAUGHLIN AFB	TX	MPAR	MPAR (3: 45°–315°)	None	None
KDGX	JACKSON/BRANDON	MS	None	None	None	None
KDIX	PHILADELPHIA	NJ	MPAR (2: 45°–225°)	None	None	None
KDLH	DULUTH	MN	None	None	None	None
KDMX	DES MOINES	IA	None	None	None	None
KDOX	DOVER AFB	DE	MPAR	MPAR	MPAR	MPAR
KDTX	DETROIT	MI	None	None	None	None
KDVN	QUAD CITIES	IA	None	None	None	None
KDYX	DYESS AFB	TX	None	None	None	None
KEAX	PLEASANT HILL	MO	MPAR (3: 0°–270°)	MPAR (3: 0°–270°)	None	None

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KEMX	TUCSON	AZ	MPAR	MPAR	MPAR	MPAR
KENX	ALBANY	NY	None	None	None	None
KEOX	FT RUCKER	AL	None	MPAR	None	MPAR
KEPZ	EL PASO	NM	MPAR	None	MPAR	None
KESX	LAS VEGAS	NV	MPAR	MPAR	MPAR	MPAR
KEVX	EGLIN AFB	FL	MPAR	None	MPAR	None
KEWX	AUSTIN/SAN ANTONIO	TX	MPAR	None	MPAR	None
KEYX	EDWARDS AFB	CA	MPAR	None	MPAR	None
KFCX	ROANOKE	VA	MPAR (3: 210°–120°)	MPAR (3: 210°–120°)	MPAR (3: 210°–120°)	MPAR (3: 210°–120°)
KFDR	ALTUS AFB	OK	MPAR	MPAR	None	None
KFDX	CANNON AFB	NM	MPAR	None	MPAR	None
KFFC	ATLANTA	GA	None	None	None	None
KFSD	SIOUX FALLS	SD	None	None	None	None
KFSX	FLAGSTAFF	AZ	MPAR	MPAR	MPAR	MPAR
KFTG	DENVER	CO	None	None	None	None
KFWS	DALLAS/FT WORTH	TX	None	None	None	None
KGGW	GLASGOW	MT	MPAR	MPAR	MPAR	MPAR
KGJX	GRAND JUNCTION	CO	MPAR	MPAR	MPAR	MPAR
KGLD	GOODLAND	KS	MPAR	MPAR	MPAR	MPAR
KGRB	GREEN BAY	WI	None	None	None	None
KGRK	FT HOOD	TX	MPAR	None	MPAR	None
KGRR	GRAND RAPIDS	MI	None	None	None	None
KGSP	GREER	SC	None	None	None	None
KGWX	COLUMBUS AFB	MS	MPAR (3: 120°–30°)	MPAR (3: 120°–30°)	None	None
KGYX	PORTLAND	ME	None	None	None	None
KHDX	HOLLOMAN AFB	NM	MPAR	None	None	None

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KHGX	HOUSTON	TX	None	None	None	None
KHNX	SAN JOAQUIN VALLEY	CA	None	None	None	None
KHPX	FT CAMPBELL	KY	MPAR (3: 140°–50°)	MPAR (2: 120°–300°)	None	None
KHTX	NORTHEAST ALABAMA	AL	MPAR	MPAR	MPAR	MPAR
KICT	WICHITA	KS	None	None	None	None
KICX	CEDAR CITY	UT	MPAR	None	MPAR	None
KILN	CINCINNATI	OH	None	None	None	None
KILX	LINCOLN	IL	MPAR (3: 45°–315°)	MPAR (3: 45°–315°)	MPAR (3: 45°–315°)	MPAR (3: 45°–315°)
KIND	INDIANAPOLIS	IN	None	None	None	None
KINX	TULSA	OK	None	None	None	None
KIWA	PHOENIX	AZ	None	None	None	None
KIWX	NORTHERN INDIANA	IN	MPAR (2: 0°–90°, 180°–270°)	MPAR (2: 0°–90°, 180°–270°)	MPAR (2: 0°–90°, 180°–270°)	MPAR (2: 0°–90°, 180°–270°)
KJAX	JACKSONVILLE	FL	None	None	None	None
KJGX	ROBINS AFB	GA	None	None	None	None
KJKL	JACKSON	KY	MPAR	MPAR	MPAR	MPAR
KLBB	LUBBOCK	TX	None	None	None	None
KLCH	LAKE CHARLES	LA	None	None	None	None
KLGX	LANGLEY HILL	WA	MPAR	MPAR	MPAR	MPAR
KLIX	SLIDELL	LA	None	None	None	None
KLNX	NORTH PLATTE	NE	MPAR	MPAR	MPAR	MPAR
KLOT	CHICAGO	IL	None	None	None	None
KLRX	ELKO	NV	MPAR	MPAR	MPAR	MPAR
KLSX	ST LOUIS	MO	None	None	None	None
KLTX	WILMINGTON	NC	None	None	None	None
KLVX	LOUISVILLE	KY	None	None	None	None

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KLWX	STERLING	VA	None	None	None	None
KLZK	LITTLE ROCK	AR	None	None	None	None
KMAF	MIDLAND/ODESSA	TX	None	None	None	None
KMAX	MEDFORD	OR	MPAR	MPAR (3: 135°–45°)	MPAR	MPAR (3: 135°–45°)
KMBX	MINOT AFB	ND	MPAR	MPAR	None	None
KMHX	MOREHEAD CITY	NC	MPAR	MPAR	None	None
KMKX	MILWAUKEE	WI	None	None	None	None
KMLB	MELBOURNE	FL	None	None	None	None
KMOB	MOBILE	AL	None	None	None	None
KMPX	MINNEAPOLIS	MN	None	None	None	None
KMQT	MARQUETTE	MI	MPAR	MPAR	MPAR	MPAR
KMRX	KNOXVILLE	TN	MPAR	MPAR	MPAR	MPAR
KMSX	MISSOULA	MT	MPAR	MPAR	MPAR	MPAR
KMTX	SALT LAKE CITY	UT	MPAR	MPAR	MPAR	None
KMUX	SAN FRANCISCO	CA	None	None	None	None
KMVX	FARGO/GRAND FORKS	ND	MPAR	None	None	None
KMXX	MAXWELL AFB	AL	None	None	None	None
KNKX	SAN DIEGO	CA	None	None	None	None
KNQA	MEMPHIS	TN	None	None	None	None
KOAX	OMAHA	NE	None	None	None	None
KOHX	NASHVILLE	TN	None	None	None	None
KOKX	BROOKHAVEN	NY	MPAR (3: 315°–225°)	None	MPAR (3: 315°–225°)	None
KOTX	SPOKANE	WA	None	None	None	None
KPAH	PADUCAH	KY	MPAR (3: 120°–30°)	MPAR (3: 120°–30°)	MPAR (3: 120°–30°)	MPAR (3: 120°–30°)
KPBZ	PITTSBURGH	PA	None	None	None	None

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KPDT	PENDLETON	OR	MPAR	MPAR	MPAR	MPAR
KPOE	FT POLK	LA	MPAR (2: 300°–120°)	MPAR (2: 300°–120°)	None	None
KPUX	PUEBLO	CO	None	None	None	None
KRAX	RALEIGH/DURHAM	NC	None	None	None	None
KRGX	RENO	NV	MPAR	MPAR	MPAR	MPAR
KRIW	RIVERTON/LANDER	WY	MPAR	MPAR	MPAR	MPAR
KRLX	CHARLESTON	WV	None	None	None	None
KRTX	PORTLAND	OR	MPAR	MPAR	MPAR	MPAR
KSFX	POCATELLO	ID	MPAR	MPAR	MPAR	MPAR
KSGF	SPRINGFIELD	MO	None	None	None	None
KSHV	SHREVEPORT	LA	None	None	None	None
KSJT	SAN ANGELO	TX	None	None	None	None
KSOX	SANTA ANA MTS	CA	MPAR (1: 60°–150°)	None	MPAR (1: 60°–150°)	None
KSRX	WESTERN ARKANSAS	AR	None	None	None	None
KTBW	TAMPA	FL	None	None	None	None
KTFX	GREAT FALLS	MT	None	None	None	None
KTLH	TALLAHASSEE	MT	None	None	None	None
KTLX	NORMAN	FL	None	None	None	None
KTWX	TOPEKA	KS	MPAR	MPAR	None	None
KTYX	FT DRUM	NY	MPAR (3: 240°–150°)	MPAR (3: 240°–150°)	None	None
KUDX	RAPID CITY	SD	MPAR	MPAR	None	None
KUEX	GRAND ISLAND	NE	MPAR	MPAR	MPAR	MPAR
KVAX	MOODY AFB	GA	MPAR	MPAR	None	None
KVBX	VANDENBERG AFB	CA	MPAR	None	MPAR	None
KVNX	VANCE AFB	OK	MPAR	MPAR	None	None

Site ID	Site Name	State	Scenario 2	Scenario 3	Scenario 2G	Scenario 3G
KVTX	LOS ANGELES	CA	MPAR	MPAR	MPAR	MPAR
KVWX	EVANSVILLE	IN	None	None	None	None
KYUX	YUMA	AZ	MPAR	MPAR	None	None
PABC	BETHEL	AK	MPAR	MPAR	MPAR	MPAR
PACG	SITKA	AK	MPAR	MPAR	MPAR	MPAR
PAEC	NOME	AK	MPAR	MPAR	MPAR	MPAR
PAHG	ANCHORAGE	AK	MPAR	MPAR	MPAR	MPAR
PAIH	MIDDLETON ISLAND	AK	MPAR	MPAR	MPAR	MPAR
PAKC	KING SALMON	AK	MPAR	MPAR	MPAR	MPAR
PAPD	FAIRBANKS	AK	MPAR	MPAR	MPAR	MPAR
PGUA	ANDERSEN AFB	GU	MPAR	None	MPAR	None
PHKI	SOUTH KAUAI	HI	MPAR	MPAR	MPAR	MPAR
PHKM	KAMUELA/KOHALA APT	HI	MPAR	MPAR	MPAR	MPAR
PHMO	MOLOKAI	HI	MPAR	MPAR	MPAR	MPAR
PHWA	SOUTH SHORE	HI	MPAR	MPAR	MPAR	MPAR
TJUA	SAN JUAN	PR	MPAR (3: 45°–315°)	MPAR (2: 90°–270°)	MPAR (3: 45°–315°)	MPAR (2: 90°–270°)

TABLE A-4

CARSR Sites

Site ID	Site Name	State	Original Type	Scenario 3	Scenario 3G
AEX	ALEXANDRIA	LA	FPS-20A	None	None
AMA	AMARILLO	TX	FPS-67B	None	None
ATL	MARIETTA	GA	ARSR-1	None	None
BAM	BATTLE MOUNTAIN	NV	ARSR-2	MPAR	None
BQN	PUNTA BORINQUEN	PR	FPS-93A	MPAR	MPAR
CDC	CEDAR CITY	UT	ARSR-2	MPAR	MPAR
CLE	BRECKSVILLE (CLEVELAND)	OH	ARSR-1	None	None
CPV	COOPERSVILLE	MI	FPS-66A	None	None
DSV	DANSVILLE	NY	ARSR-1	None	None
ENA	KENAI	AK	ARSR-3	None	None
FLX	FALLON	NV	FPS-66A	MPAR	None
FPK	SALT LAKE CITY (FRANCIS PEAK)	UT	ARSR-1	MPAR (2: 350°–170°)	MPAR (2: 350°–170°)
FTW	KELLER	TX	ARSR-1	None	None
GCK	GARDEN CITY	KS	ARSR-2	None	None
GJT	GRAND JUNCTION	CO	ARSR-2	MPAR	MPAR
GUP	GALLUP (FARMINGTON)	NM	ARSR-2	MPAR	MPAR
HOU	HOUSTON (ELLINGTON AFB)	TX	ARSR-1	None	None
HTI	HUTCHINSON	KS	FPS-66A	None	None
IND	INDIANAPOLIS	IN	ARSR-1	None	None
IRK	KIRKSVILLE	MO	ARSR-3	MPAR	MPAR
JOL	ELWOOD (JOLIET)	IL	ARSR-3	None	None
LBF	NORTH PLATTE	NE	ARSR-2	None	None
LMT	KLAMATH FALLS	OR	FPS-67B	MPAR	MPAR
LSK	LUSK	WY	ARSR-2	MPAR	MPAR
MGM	MONTGOMERY	AL	ARSR-1	None	None
OKC	TINKER AFB	OK	FPS-67B	None	None

Site ID	Site Name	State	Original Type	Scenario 3	Scenario 3G
PHX	PHOENIX (HUMBOLDT)	AZ	ARSR-1	None	None
PIT	OAKDALE	PA	FPS-67B	None	None
QAS	ANGEL PEAK	NV	FPS-20A	MPAR	MPAR
QBE	BEDFORD	VA	ARSR-3	None	None
QBN	BINNS HALL	VA	ARSR-3	None	None
QBZ	OSKALOOSA	KS	ARSR-2	None	None
QCF	CLEARFIELD	PA	ARSR-3	None	None
QCK	CASCADE (BOISE)	ID	ARSR-2	MPAR	MPAR
QDT	CANTON (DETROIT)	MI	ARSR-1	None	None
QHA	CUMMINGTON	MA	FPS-67	None	None
QHB	ST ALBANS	VT	FPS-67B	MPAR	MPAR
QHN	ASHBURN	GA	ARSR-1	None	None
QHO	OMAHA	NE	FPS-66A	None	None
QHZ	HORICON	WI	ARSR-2	None	None
QJB	GETTYSBURG	SD	FPS-67B	None	None
QJC	TYLER	MN	ARSR-2	None	None
QJE	APPLE VALLEY	MN	ARSR-1	None	None
QJO	ARLINGTON	IA	ARSR-3	None	None
QJQ	PICO DEL ESTE	PR	FPS-67A	MPAR (1: 90°–180°)	MPAR (1: 90°–180°)
QLA	SAN PEDRO	CA	ARSR-1	MPAR	MPAR
QNK	LINCOLNTON	GA	ARSR-3	None	None
QNM	NEWPORT	MS	ARSR-3	None	None
QOJ	JOELTON (NASHVILLE)	TN	ARSR-1	None	None
QPC	HALEYVILLE	AL	FPS-67B	None	None
QPK	PARKER	CO	ARSR-1	MPAR	MPAR
QPL	THE PLAINS	VA	ARSR-3	None	None
QRB	CITRONELLE	AL	ARSR-2	None	None
QRC	BENTON	PA	FPS-67B	None	None
QRI	LYNCH	KY	ARSR-2	None	None

Site ID	Site Name	State	Original Type	Scenario 3	Scenario 3G
QRL	BENSON	NC	ARSR-1	None	None
QRM	MAIDEN	NC	ARSR-1	None	None
QSA	WEST MESA	NM	FPS-66A	None	None
QSI	LOVELL	WY	ARSR-2	MPAR	MPAR
QSR	BORON	CA	FPS-67B	MPAR	MPAR
QTZ	LAGRANGE	IN	ARSR-1	None	None
QUZ	HANNA CITY	IL	FPS-67B	None	None
QVA	ASHTON	ID	ARSR-2	MPAR	MPAR
QVN	FOSSIL	OR	ARSR-3	MPAR	MPAR
QWC	MESA RICA	NM	ARSR-1	MPAR	MPAR
QWO	LONDON	OH	ARSR-1	None	None
QXP	SELIGMAN	AZ	ARSR-3	MPAR	MPAR
QXR	RUSSELLVILLE	AR	FPS-67A	None	None
QXS	ODESSA	TX	ARSR-1	None	None
QYB	BYHALIA (MEMPHIS)	MS	ARSR-1	None	None
QYS	ROGERS	TX	ARSR-1	MPAR	MPAR
RBL	RED BLUFF	CA	FPS-67B	MPAR	MPAR
RKS	ROCK SPRINGS	WY	ARSR-2	MPAR	MPAR
SEA	SEATTLE (FT LAWTON)	WA	ARSR-1	None	None
SNI	SAN NICOLAS	CA	ARSR-3	MPAR (3: 100°–10°)	MPAR (3: 100°–10°)
STL	ST LOUIS (OVERLAND)	MO	ARSR-1	None	None
SVC	SILVER CITY	NM	ARSR-2	MPAR	MPAR
TAD	TRINIDAD	CO	ARSR-2	MPAR	MPAR
TXK	TEXARKANA	AR	FPS-67	None	None

TABLE A-5

ARSR-4 Sites

Site ID	Site Name	State	Scenario 3	Scenario 3G
AJO	AJO	AZ	MPAR	MPAR
CTY	CROSS CITY	FL	MPAR (2: 120°–300°)	MPAR (2: 120°–300°)
DMN	DEMING (MAGDALEN)	NM	MPAR	MPAR
FN7	FT GREEN	FL	MPAR (2: 30°–210°)	MPAR (2: 30°–210°)
GFA	BOOTLEGGER RIDGE (MALMSTROM)	MT	MPAR	MPAR
LCH	LAKE CHARLES	LA	MPAR	MPAR
MLB	MELBOURNE	FL	MPAR (2: 45°–225°)	MPAR (2: 45°–225°)
NBW	GUANTANAMO	CU	MPAR	MPAR
NEN	WHITEHOUSE (JACKSONVILLE)	FL	MPAR (2: 0°–180°)	None
NEW	SLIDELL (NEW ORLEANS)	LA	MPAR (3: 270°–180°)	MPAR (3: 270°–180°)
NQX	KEY WEST	FL	MPAR	None
NSD	SAN CLEMENTE	CA	MPAR	MPAR
PAM	TYNDALL AFB	FL	MPAR	MPAR
PRB	PASO ROBLES	CA	MPAR	MPAR
QEA	NORTH TRURO	MA	MPAR	MPAR
QFI	FINLEY	ND	MPAR	MPAR
QGV	FT FISHER	NC	MPAR	MPAR
QIE	GIBBSBORO	NJ	MPAR (2: 15°–195°)	None
QJA	EMPIRE	MI	None	None
QJD	NASHWAUK	MN	MPAR (3: 180°–90°)	MPAR (3: 180°–90°)
QKA	MT KAALA	HI	MPAR	MPAR
QKW	MAKAH	WA	MPAR	MPAR
QLR	MT SANTA ROSA	GU	MPAR	MPAR
QLS	LAKESIDE	MT	MPAR	MPAR
QM8	TAMIAMI	FL	MPAR (3: 45°–315°)	None
QMI	MICA PEAK	WA	MPAR	MPAR
QMV	MILL VALLEY	CA	MPAR	MPAR

Site ID	Site Name	State	Scenario 3	Scenario 3G
QNA	MORALES	TX	MPAR	MPAR
QNW	EAGLE PEAK	TX	MPAR	MPAR
QOM	KING MOUNTAIN	TX	MPAR	MPAR
QRJ	JEDBURG	SC	MPAR	MPAR
QRW	MT LAGUNA	CA	MPAR	MPAR
QVH	RIVERHEAD (SUFFOLK)	NY	MPAR (3: 315°–225°)	MPAR (3: 315°–225°)
QVR	OCEANA	VA	MPAR	None
QWA	WATFORD CITY	ND	MPAR	MPAR
QXU	UTICA (REMSEN)	NY	None	None
QYA	BUCKS HARBOR	ME	MPAR	MPAR
QYD	CARIBOU	ME	MPAR	MPAR
QZA	OILTON	TX	MPAR	MPAR
QZZ	RAINBOW RIDGE	CA	MPAR	MPAR
RSG	ROCKSPRINGS	TX	MPAR	MPAR
SLE	SALEM	OR	MPAR	MPAR
VBG	VANDENBERG AFB	CA	MPAR	MPAR

TABLE A-6

GPN Sites

Site ID	Site Name	State	Type	Owner	Scenario 1G	Scenario 2G	Scenario 3G
APN	ALPENA	MI	GPN-30	AF	TMPAR	TMPAR	TMPAR
BYS	VELVET PEAK	CA	ASR-11	AR	TMPAR	TMPAR	TMPAR
CBM	COLUMBUS	MS	GPN-30	AF	TMPAR	MPAR	MPAR
CVS	CANNON	NM	GPN-30	AF	TMPAR	TMPAR	TMPAR
DGDQ	HILL AFB- CEDAR MTN	UT	ASR-9	AF	TMPAR	TMPAR	TMPAR
DLF	LAUGHLIN	TX	GPN-30	AF	TMPAR	MPAR	MPAR
DOV	DOVER	DE	GPN-30	AF	TMPAR	TMPAR	TMPAR
EDW	EDWARDS AFB	CA	ASR-11	AF	TMPAR	TMPAR	TMPAR
END	VANCE	OK	GPN-30	AF	TMPAR	MPAR	MPAR

Site ID	Site Name	State	Type	Owner	Scenario 1G	Scenario 2G	Scenario 3G
FBG	FT BRAGG	NC	GPN-30	AR	TMPAR	TMPAR	TMPAR
FHU	FT HUACHUCA	AZ	GPN-30	AR	TMPAR	TMPAR	TMPAR
FRI	FT RILEY	KS	GPN-30	AR	TMPAR	MPAR	MPAR
FSI	HENRY POST AAF	OK	ASR-8	AR	TMPAR	TMPAR	TMPAR
GAB	GABBS	NV	GPN-27	N	TMPAR	TMPAR	TMPAR
GSB	SEYMOUR JOHNSON	NC	GPN-30	AF	TMPAR	TMPAR	TMPAR
GTB	FT DRUM	NY	GPN-30	AR	TMPAR	MPAR	MPAR
GUS	GRISSOM	IN	GPN-30	AF	TMPAR	TMPAR	TMPAR
HLR	FT HOOD	TX	GPN-30	AR	TMPAR	TMPAR	TMPAR
HMN	HOLLOMAN	NM	GPN-30	AF	TMPAR	MPAR	TMPAR
HNG	KANEOHE	HI	GPN-30	MC	TMPAR	TMPAR	TMPAR
HOP	FT CAMPBELL	KY	GPN-30	AR	TMPAR	MPAR	MPAR
HST	HOMESTEAD	FL	GPN-30	AF	TMPAR	TMPAR	MPAR (3: 45°–315°)
ILN	WILMINGTON	OH	ASR-9	NG	TMPAR	TMPAR	TMPAR
IYK	INDIAN WELLS VALLEY	CA	ASR-8	N	TMPAR	TMPAR	TMPAR
JST	JOHNSTOWN CAMBRIA	PA	GPN-30	AF	TMPAR	TMPAR	TMPAR
KWA	KWAJALEIN	MHL	GPN-30	AR	TMPAR	TMPAR	TMPAR
LHW	FT STEWART	GA	GPN-30	AR	TMPAR	TMPAR	TMPAR
LTS	ALTUS	OK	GPN-30	AF	TMPAR	MPAR	MPAR
LUF	LUKE	AZ	GPN-30	AF	TMPAR	TMPAR	TMPAR
MGE	DOBBINS	GA	GPN-30	AF	TMPAR	TMPAR	TMPAR
MIB	MINOT	ND	GPN-30	AF	TMPAR	MPAR	MPAR
MSGD	HILL AFB- BOVINE	UT	ASR-9	AF	TMPAR	TMPAR	MPAR
MTC	SELFRIDGE	MI	GPN-30	AF	TMPAR	TMPAR	TMPAR
MUO	MTN HOME	ID	GPN-30	AF	TMPAR	TMPAR	TMPAR
NBC	BEAUFORT	SC	GPN-30	MC	TMPAR	TMPAR	TMPAR
NBG	NEW ORLEANS	LA	GPN-27	N	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Owner	Scenario 1G	Scenario 2G	Scenario 3G
NCA	NEW RIVER	NC	GPN-30	MC	TMPAR	TMPAR	TMPAR
NFL	FALLON	NV	GPN-30	N	TMPAR	TMPAR	TMPAR
NFW	FT WORTH	TX	GPN-30	N	TMPAR	TMPAR	TMPAR
NHK	PATUXENT RIVER	MD	GPN-30	N	TMPAR	TMPAR	TMPAR
NID	SEARLES VALLEY	CA	ASR-8	N	TMPAR	TMPAR	TMPAR
NID2	PANAMINT VALLEY	CA	ASR-11	N	TMPAR	TMPAR	TMPAR
NIP	JACKSONVILLE	FL	GPN-30	N	TMPAR	TMPAR	MPAR
NKT	CHERRY PT	NC	GPN-30	MC	TMPAR	MPAR	MPAR
NLC	LEMOORE	CA	GPN-30	N	TMPAR	TMPAR	TMPAR
NMM	MERIDIAN	MS	ASR-8	N	TMPAR	TMPAR	TMPAR
NNP	NEW PASS	NV	GPN-27	N	TMPAR	TMPAR	MPAR
NQI	KINGSVILLE	TX	GPN-30	N	TMPAR	TMPAR	TMPAR
NQX	BOCA CHICA	FL	GPN-30	N	TMPAR	MPAR	MPAR
NRB	MAYPORT	FL	GPN-30	N	TMPAR	TMPAR	TMPAR
NSC	WHITING FIELD NAS	FL	ASR-11	N	TMPAR	TMPAR	TMPAR
NTD	PT MUGU	CA	GPN-30	N	TMPAR	TMPAR	TMPAR
NTU	OCEANA	VA	GPN-30	N	TMPAR	TMPAR	MPAR
NUC	SAN CLEMENTE	CA	GPN-30	N	TMPAR	TMPAR	TMPAR
NUW	WHIDBEY IS	WA	GPN-30	N	TMPAR	MPAR	MPAR
NV30	DIXIE VALLEY	NV	GPN-27	N	TMPAR	TMPAR	TMPAR
NXP	TWENTYNINE PALMS	CA	GPN-30	MC	TMPAR	TMPAR	TMPAR
NYG	QUANTICO	VA	GPN-27	MC	TMPAR	TMPAR	TMPAR
NYL	YUMA	AZ	GPN-30	MC	TMPAR	MPAR	MPAR
NZY	NORTH ISLAND	CA	GPN-30	N	TMPAR	TMPAR	TMPAR
O26	OWENS VALLEY	CA	ASR-8	N	TMPAR	TMPAR	TMPAR
PAM	TYNDALL	FL	GPN-30	AF	TMPAR	TMPAR	None
POE	FT POLK	LA	GPN-30	AR	TMPAR	MPAR	MPAR
R-358	WHITE SANDS MR C	NM	ASR-9	AR	TMPAR	TMPAR	TMPAR
R-361	WHITE SANDS MR D	NM	ASR-9	AR	TMPAR	TMPAR	TMPAR
R-363	WHITE SANDS MR E	NM	ASR-9	AR	TMPAR	TMPAR	TMPAR

Site ID	Site Name	State	Type	Owner	Scenario 1G	Scenario 2G	Scenario 3G
RCA	ELLSWORTH	SD	GPN-30	AF	TMPAR	MPAR	MPAR
RDR	GRAND FORKS	ND	GPN-30	AF	TMPAR	MPAR	TMPAR
RIV	MARCH	CA	GPN-30	AF	TMPAR	TMPAR	TMPAR
SPS	SHEPPARD	TX	GPN-30	AF	TMPAR	TMPAR	TMPAR
SSC	SHAW	SC	GPN-30	AF	TMPAR	TMPAR	TMPAR
SUU	TRAVIS	CA	GPN-30	AF	TMPAR	MPAR	TMPAR
SZL	WHITEMAN	MO	GPN-30	AF	TMPAR	MPAR	MPAR
TPN	TOLICHA PEAK	NV	GPN-30	AF	TMPAR	TMPAR	TMPAR
VAD	MOODY	GA	GPN-30	AF	TMPAR	MPAR	MPAR
VOK	VOLK FIELD	WI	GPN-30	AF	TMPAR	TMPAR	TMPAR
VPS	EGLIN	FL	GPN-30	AF	TMPAR	TMPAR	TMPAR
WAL	WALLOPS ISLAND	VA	GPN-27	N	TMPAR	TMPAR	TMPAR
WRI	MCGUIRE	NJ	GPN-30	AF	TMPAR	MPAR	MPAR
XFP4	HILL AFB- TROUT CREEK	UT	ASR-9	AF	TMPAR	TMPAR	TMPAR
XMR	KENNEDY SC	FL	GPN-30	AF	TMPAR	TMPAR	TMPAR

GLOSSARY

3D	three dimensional
A/C	aircraft
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	above ground level
ARSR	Air Route Surveillance Radar
ASR	Airport Surveillance Radar
CARSR	Common Air Route Surveillance Radar
CONUS	contiguous United States
DTED	Digital Terrain Elevation Data
FAA	Federal Aviation Administration
FPS	Fixed Position System
GPN	Ground Position Navigation
GPS	Global Positioning System
ITWS	Integrated Terminal Weather System
MPAR	Multifunction Phased Array Radar
MSL	mean sea level
NAS	National Airspace System
NEXRAD	Next Generation Radar
NextGen	Next Generation Air Transportation System
nmi	nautical mile

NOAA	National Oceanic and Atmospheric Administration
NSWRC	NextGen Surveillance Weather Radar Capability
NWS	National Weather Service
SDO	super density operations
SRTM	Shuttle Radar Tomography Mission
STC	sensitivity time control
TDWR	Terminal Doppler Weather Radar
TMPAR	Terminal Multifunction Phased Array Radar
VCP	volume coverage pattern
Wx	weather
WSP	Weather Systems Processor
WSR-88D	Weather Surveillance Radar 1988-Doppler

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