J1.10 FAA SURVEILLANCE RADAR DATA AS A COMPLEMENT TO THE WSR-88D NETWORK *

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1. INTRODUCTION

The U.S. Federal Aviation Administration (FAA) operates over 400 C- to L-band surveillance radars—Airport Surveillance Radars (ASRs), Air Route Surveillance Radars (ARSRs) and Terminal Doppler Weather Radars (TDWRs). Current generation terminal and en route aircraft surveillance radars (ASR-9, ASR-11 and ARSR-4) feature dedicated digital processing channels that measure and display precipitation reflectivity. Some of these "weather channels" will be upgraded to measure Doppler velocity, supporting, for example, wind shear detection at air terminals. The Terminal Doppler Weather Radar is a high quality dedicated meteorological surveillance radar deployed near many of the larger airports in the U.S.

In this paper we consider how these radars could complement the WSR-88D network in providing a variety of meteorological services to the U.S. public. Potential benefits from a combined radar network would accrue from significantly increased radar density and the more rapid temporal updates of the FAA radars. Convective weather monitoring and forecasting, hydrological measurements and services to aviation are examples of areas where significant improvements could be expected.

Section 2 reviews the status of the FAA radars—their parameters, locations and capabilities. We also note the progress of various upgrade programs that will increase their weather surveillance capabilities substantially. In Section 3, we discuss benefits that would result from their usage in conjunction with the WSR-88D network. Finally, we discuss technological developments that will facilitate realization of these benefits.

2. FAA RADAR SUMMARIES

Figure 1 maps the TDWR, ASR-9, ASR-11 and ARSR-4 networks. Note that additional ASR-9s and ASR-11s at U.S. military bases are not shown in this figure. Table 1 summarizes the parameters of these radars.

2.1. TDWR

Deployment of the TDWR network is nearly complete. Only at two airports (Chicago-Midway and John F. Kennedy) is installation still in progress, a result of earlier site acquisition problems. TDWR features comparable sensitivity to the WSR-88D when the latter radar is in convective weather transmit mode. TDWR's cross range resolution is a factor of two higher than the WSR-88D and it scans the airspace it covers significantly faster. Typically, the TDWR is sited nearer to major cities than the WSR-88D. The TDWR base data generation algorithms seek to maintain a high level of data quality (e.g., robust ground clutter suppression and clutter residue editing) to support fully automated low altitude wind shear detection.

The TDWR Program Support Facility is working to rehost the Radar Product Generator (RPG) function onto a more capable, modern computer system. This will enable the radar to execute a complete, 360^{o} volume scan pattern while maintaining an update rate sufficient to support its low altitude wind shear detection mission. The volume scan will require about three minutes and will continue to feature surface tilts every 60 seconds. This RPG upgrade is scheduled to take place in 2001.

The FAA also recognizes the benefits of replacing the TDWR Radar Data Acquisition (RDA) computer with a contemporary processor. Functional benefits could include improved base data generation algorithms:

(i) Greater processing range for reflectivity and Doppler velocity imagery;

(ii) More robust treatment of range-Doppler ambiguities; for example, through the use of a multi-PRI pulse sequence and/or pulse-to-pulse phase coding; and

(iii) Realization of the inherent $1/2^{o}$ azimuth beamwidth, currently "spoiled" to 1^{o} by the coherent processing operations.

The RDA upgrade effort is expected to commence in 2002.

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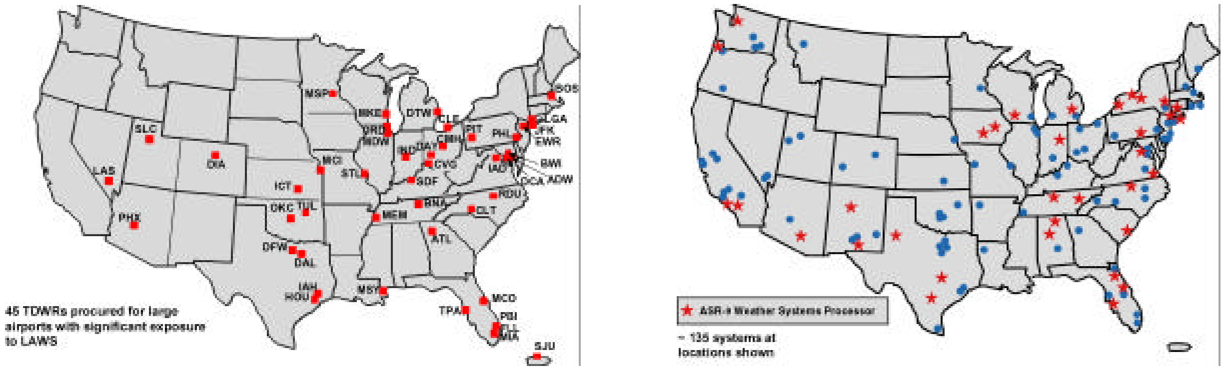
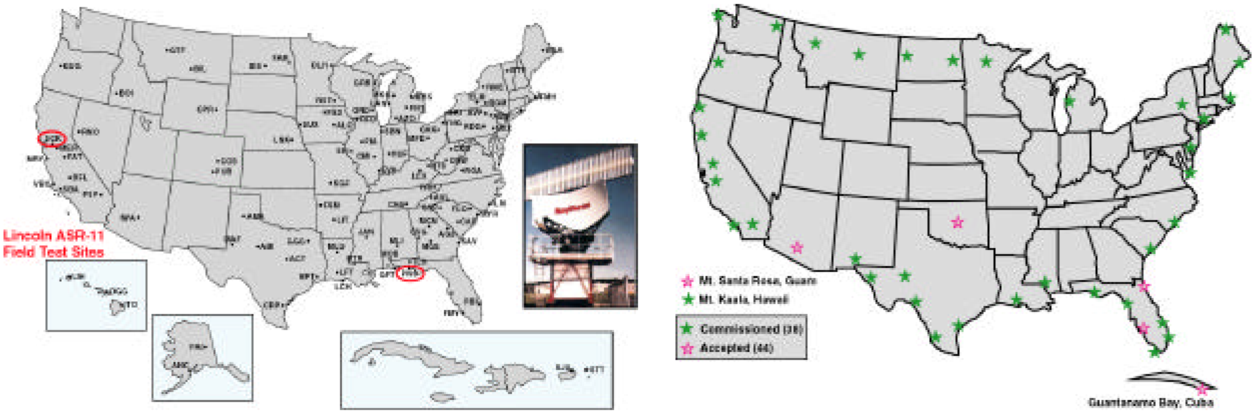


TDWRs ASR-9s



ASR-11s ARSR-4s

Figure 1. Locations of FAA surveillance radars.

Table 1. Parameters of the FAA Surveillance Radars

	TDWR (Raytheon)	ASR-9 (Northrop Grumman)	ASR-11 (Raytheon)	ARSR-4 (Northrop Grumman)
Transmitter				
Frequency	5.5 - 5.65 GHz ~ C Band	2.7-2.9 GHz	2.7-2.9 GHz	1.2-1.4 GHz
Polarization	Linear	Linear or Circular	Linear or Circular	Linear or Circular
Peak Power	250 KW	1.1 MW	20 kw	60 kw
Pulse Width	1.1 µs	1.0 µs	1.0 µs, 80 µs	150 µs
PRF	2000 (max)	2 CPIs (~ 1000 Hz avg.)	4 CPIs (~ 1000 Hz avg.)	9-pulse CPI at variable spacing (288 Hz avg)
Receiver				
Sensitivity	0 dBz @ 190 km 1 m^2 @ 460 km	0 dBz @ 20 km 1 m^2 @ 111 km	0 dBz @ 20 km 1 m^2 @ 111 km *	0 dBz @ 10 km 1 m^2 @ 370 km
Antenna				
Elevation Beamwidth	0.55 Degrees (min)	5 Degrees	5 Degrees	2 Degrees (stacked)
Azimuth Beamwidth	0.55 Degrees	1.4 Degrees	1.4 Degrees	1.4 Degrees
Power Gain	50 dB	34 dB	34 dB	35 dB (transmit), 40 dB (receive)
Rotation Rate	5 RPM (max)	12.5 RPM	12.5 RPM	5.0 RPM
* 17dB sensitivity reduction in short-pulse processing range (0 - 6.5 nmi)				

2.2. ASR-9

The ASR-9 network is fully deployed. The radar features a dedicated processing channel to measure and display the precipitation reflectivity field measured through its vertically integrating fan-shaped elevation beam. These measurements are updated every 30 seconds. At 35 sites, a Weather Systems Processor (WSP) upgrade will be added to the ASR-9 to measure Doppler wind velocity and thereby support detection of low altitude wind shear. The WSP also improves the quality of the ASR-9's precipitation reflectivity measurements by eliminating ground clutter breakthrough that may occur during ducting or anomalous propagation conditions. The WSP provides full resolution reflectivity and velocity imagery out to the ASR-9's instrumented range of 60 nmi; the images are updated every antenna sweep (4.8 seconds) out to 15 nmi where the wind shear detection algorithms operate, and every minute at greater ranges. WSP deployments will take place in 2001 and 2002.

The FAA is developing requirements for a broad-based upgrade program for the ASR-9 processor. This could increase the radars' weather surveillance capability by: (1) embedding WSP functionality in the ASR-9 processor at all sites; (2) extending the instrumented range for weather reflectivity measurements from 60 to 120 nmi; (3) improving the correspondence between the radar's vertically integrated precipitation reflectivity measurements and physical quantities such as vertically integrated liquid water. This latter enhancement can be realized using adaptive scaling of the received power measurements based on ancillary input on storm vertical structure from more slowly scanning pencil beam operational weather radars.

2.3. ASR-11

The FAA and USAF are jointly procuring a second buy of terminal surveillance radars for airfields that did not previously receive the ASR-9. Parameters of the ASR-11 are essentially identical to those of the ASR-9, with two important exceptions. A solid state, low-peak power transmitter with pulse compression technology is used in place of the ASR-9's short, high peak-power pulse. This provides similar energy on target at long range but results in significantly reduced sensitivity at short range (<6.5 nmi) where the ASR-11 cannot utilize its "long pulse". In addition, the ASR-11's pulse sequence utilizes frequency diversity in a way that limits coherent processing dwells to a very small number of pulses. This feature is advantageous to its target detection role but reduces the Doppler resolution available for weather processing.

Like the ASR-9, the ASR-11 features a dedicated weather reflectivity processor that outputs "six level" maps of precipitation reflectivity. As a result of the two factors described above, the ASR-11 is less suitable for Doppler wind measurement and wind shear detection than the ASR-9. No plans exist currently to add the WSP to this radar.

2.4. ARSR-4

ARSR-4 is a long-range surveillance radar deployed around the perimeter of the CONUS. It operates at L-band and utilizes a phased feed array assembly that allows for the formation of ten 2^{o} elevation receive beams. This elevation stack is swept in azimuth at a rate of 5 RPM.

The ARSR-4 includes a five-level reflectivity processor. This has somewhat limited capability owing to the fact that only one of the available pencil beam receive paths may be processed at a given range, resulting in the likelihood of over- or under-shoot of the highest reflectivity in a storm. In addition, the minimum reflectivity level currently output by the processor is 30 dBz. (FAA is assessing whether this could be reduced.)

FAA and NWS are evaluating the capability of the ARSR-4 to provide both improved reflectivity and Doppler wind measurements via addition of an outboard Doppler weather processor. During CY 2000/2001 in-phase and quadrature samples from an operational ARSR-4 will be recorded. These will be processed offline to assess candidate base data generation algorithms and the quality of the resulting imagery. Given favorable results, a real-time processor will be fabricated and demonstrated in an operational setting. If this concept exploration program is successful, it is likely that many or all ARSR-4s will be retrofitted with an operational Doppler weather processing channel.

3. OPERATIONAL BENEFITS

In broad terms, the expected operational benefits of merging FAA radar outputs with WSR-88D data would result from two factors:

(i) Reduction in the range from the nearest radar to many areas of operational concern; and

(ii) Significant increase in the rate at which rapidly changing weather systems (e.g., severe storms) are scanned.

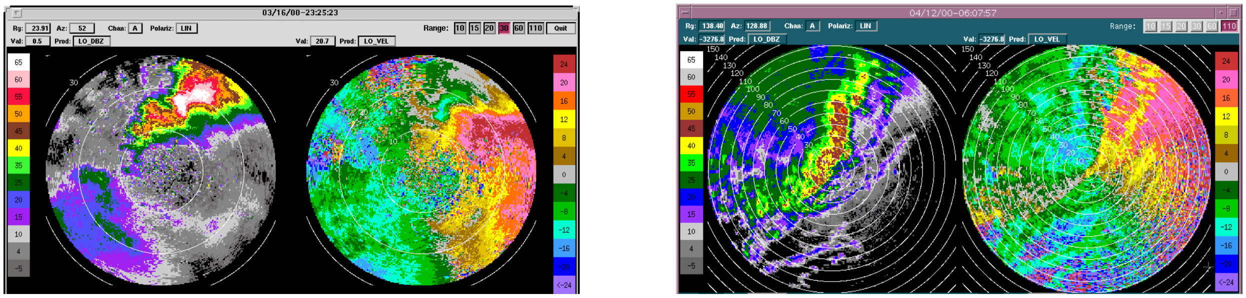
(iii) The following paragraphs briefly point out specific opportunities for improved services.

3.5. Convective Weather Warnings

Surface boundaries (gust fronts, cold fronts, sea breezes) are known to be preferred locations for both new convective growth and to play an important role in severe weather evolution (Rasumssen, et al., 2000). Beyond approximately 100 km range, the radar horizon may well be above the near-surface layer where detection of a boundary's convergent wind or reflectivity "fine line" signature is possible. Tornado vortex signatures are likewise difficult to detect at range owing to the azimuth resolution required to resolve the rotation. In both cases, convective weather warnings may be improved by incorporating data from FAA radars that are closer to areas of operational concern. The high-resolution pencil-beam TDWR is obviously the most suitable system for this role, but over more limited areas ARSR-4s and/or ASR-9s equipped with Doppler weather radar processors could likewise provide excellent viewing of these angularly limited phenomena.

Figure 2 shows examples of severe weather signatures measured by a prototype ASR-WSP at Austin, TX.

Some severe weather phenomena evolve sufficiently quickly that the 5 to 6 minute volume scan of the WSR-88D is not optimal. An example is the non-descending tornado vortex described recently by Trapp, et al. (1998). Each of the FAA radars treated here update significantly faster than the WSR-88D and can provide complementary looks at severe storms in between NEXRAD volume scans.



(a) (b)

Figure 2. Example reflectivity and Doppler velocity images of severe weather measured with an ASR-9 WSP prototype at the Austin-Bergstrom International Airport (Texas). (a) Mesocyclonic circulation associated with a tornado-producing thunderstorm on March 16, 2000. (b) Line echo wave pattern associated with severe straight line winds in thunderstorm on April 12, 2000.

3.6. Hydrological Monitoring

Quantitative precipitation rate estimates are best accomplished using radar reflectivity measurements as low in the atmosphere as practical. This minimizes errors due to evaporation and advection of the precipitation between the measurement altitude and the ground. Inclusion of FAA radars in the networks used to measure precipitation inputs over large river basins could improve the quality of the input to hydrological models in some areas. Such usage would require careful consideration of effects of possible attenuation potential for the 5 cm TDWR and the elevation fan beam of the ASR.

3.7. Wind Retrieval

The FAA's Integrated Terminal Weather System (ITWS) exploits the TDWR and WSR-88D in a quasi-dual-Doppler mode to generate a high-resolution, gridded Terminal Winds product for Air Traffic Control. The radar data are most valuable in the boundary layer where reflectivity, even under "clear" conditions, is sufficient to provide reliable Doppler velocity measurements. These measurements are augmented by other sensors—for example, wind measurements from commercial airlines—and numerical model output. These allow for product generation in areas where the radars' lines of sights do not provide independent measurements of the orthogonal wind components or where radar signal-to-noise is inadequate.

Single-Doppler radar wind retrieval methods may also benefit from inclusion of data from a second radar; for example, through data intercomparison that assists in maintaining the necessary degree of input data integrity.

3.8. Aviation Weather

In terminal airspace, FAA controllers use rapid-update weather reflectivity and Doppler measurements from the ASR and TDWR to monitor precipitation intensity and movement, and to provide wind shear alerts to pilots. Current plans for en route weather monitoring rely solely on the WSR-88D, processed for controllers by a "Weather and Radar Processor (WARP)." This will provide a meteorologist's display at the NWS Center Weather Service Unit in the en route center and will present precipitation reflectivity contours on the displays controllers use to monitor aircraft position.

A recent FAA concept exploration program will examine the utility of the faster-updating FAA radars for en route aviation weather monitoring. This Corridor Integrated Weather System (CIWS) will focus on delays associated with thunderstorms in key en route sectors such as the northeast corridor (Washington to Boston) and the Cleveland Center (e.g., Chicago to New York or Washington). The relatively high density of ASRs (see Figure 1) in these corridors would allow for a mosaiced reflectivity map with essentially no "data age" induced positional or intensity errors.

4. SUPPORTING TECHNOLOGY TRENDS

The Government and private sectors are currently pursuing Internet follow-ons such as "Next Generation Internet" and "Internet-II." These may provide a relatively low-cost communications infrastructure for moving broad band radar base data to appropriate integration processors (for example, in NWS Weather Forecast Offices). As an example, the experimental "Abilene Network" links more than 70 Universities together over 13,000 miles of circuits. Its backbone capacity is 2.4 Gbps and will likely expand.

Commercial-off-the-shelf (COTS) signal and data processors are dramatically improving in terms of cost-performance ratios. This will significantly reduce costs associated with retrofitting large numbers of FAA radars with more capable weather signal processing. It may be advantageous to develop a common weather radar signal processor for all of the systems described. Nearly-identical VME-based DSPs will be used for the NEXRAD "Open RDA" and the ASR-9 WSP described above. This platform will also likely form the basis for an enhanced ARSR-4 Doppler weather signal processor and is a suitable choice for a future TDWR RDA re-host.

Finally, the NEXRAD "Open RPG" provides a suitable base data integration platform for some of the applications described above. It has defined radar interface formats, expansible processing, and an applications development environment that will support rapid prototyping of new user products based on complementary information provided by additional radar base data streams.

5. SUMMARY AND RECOMMENDATIONS

We believe that significant operational benefits will accrue through appropriate incorporation of FAA radar data into a broad spectrum of public weather services. FAA-sponsored development and demonstration programs for these radars, and current broad technological trends, will facilitate such usage at relatively modest costs.

An appropriate next step would be to organize a regional-scale demonstration of FAA radar integration at an NWS WFO centered, for example, in a region prone to severe weather. Prototypical multi-radar processor algorithms and user products could be developed and provided in real time in an operational setting. In this way, detailed, early insights into data integration issues and user benefits could be obtained.

6. REFERENCES

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