2 FEDERAL AGENCY NEEDS THAT RADAR CAN MEET

Land-based radars are one of the primary sources of information about the state of the atmosphere and about objects in the atmosphere. The core missions of various Federal agencies drive a variety of requirements for information that radar data can support. The major current, direct applications of land-based radar are weather surveillance and aircraft surveillance. These existing applications generate a range of specifications for radar coverage, accuracy, latency, scan rate, reliability, and resolution that any replacement capability must meet or exceed.

Beyond these current direct applications are a much broader range of indirect applications of information that radar can provide about atmospheric conditions. Some of this information is already used by Federal agencies or provided to their constituencies, in support of agency missions. Many more potential applications are known and being perfected. In general, these indirect applications do not create new or different demands on basic radar unit performance parameters beyond those needed for future aircraft tracking and weather surveillance. However, the need to serve multiple information customers concurrently increases the importance of flexibility and multifunction capability for both individual radar units and the future national radar network or networks.

To establish a baseline of information requirements for which radar data could be applicable across the Federal government, the JAG/PARP developed a questionnaire (appendix G), which was sent to current Federal users of radar data. The following agencies responded:

- DOD, including U.S. Air Force, Navy, and Army users of radar data;
- NOAA/NWS;
- FAA;
- Federal Highway Administration (FHWA);
- DHS, including the U.S. Coast Guard and the Federal Emergency Management Agency (FEMA);
- U.S. Environmental Protection Agency (EPA);
- Department of Energy (DOE).

The questionnaire asked agencies to define their current radar requirements and capabilities and their anticipated future needs, including citation of any published documentation of the future needs. Specifically, the questionnaire asked:

- What phenomena must be sensed?
- What is the required temporal and spatial resolution of the data?

- What is the required volume sampling rate?
- What is the required level of system reliability?
- What coverage (horizontal and vertical) is required?
- Does the system have any size or weight constraints?
- Do the data need to be networked?

The principal radar requirements cited by respondents fell into three major application categories: weather surveillance, air traffic control (i.e., cooperative aircraft surveillance), and non-cooperative aircraft surveillance. Additional specialized needs exist that could be met by established or emerging radar applications. These more specialized applications include tracking of airborne hazards to aviation (e.g., flocking birds, smoke, or volcanic ash) and airborne hazards to populations (e.g., ATD of chemical hazardous materials or of chemical, biological, or nuclear warfare agents). Needs of individual agencies in each of the three major application areas will be described first. Section 2.3 covers all of the more specialized or "emerging" radar applications.

The questionnaire responses were used as the starting point for this chapter. To supplement the responses, JAG(PARP) members and OFCM staff gathered additional information on emerging and potential applications of radar that could serve established Federal agency roles and responsibilities. These applications are also discussed in Section 2.3.

2.1 Weather Surveillance

Weather radar data and the weather products produced with that data are currently used by numerous Federal, State, local, commercial, and private entities for the following purposes:

- Real-time nowcasting of severe weather events (tornados, hail, hurricanes, high winds);
- Nowcasting of wind shear/microbursts/wake vortices at airports;
- Locating convective cells for aviation support and general public information;
- Identification of en route icing hazards and turbulence for aviation safety;
- Locating and deriving instantaneous rates of precipitation for hydrological forecasts, general aviation, and public forecasts and safety (i.e. flood warnings, snow warnings);
- Identification of precipitation type for surface transport and weather forecasting; and
- Initialization of NWP models of winds at and near the planetary boundary layer.

Survey respondents from Federal agencies including NOAA/NWS, DOD, and FAA would like future radar systems to sense additional atmospheric parameters, such as extremely fine drizzle, non-precipitating clouds (bases and tops), aerosols, and lightning. Some of these parameters are largely transparent to the current weather radar system: the Weather Surveillance Radar 1988 Doppler (WSR-88D). Data on these phenomena would help operational aviation support and military planning, in addition to meteorological research.

2.1.1 Current Weather Radar Capabilities

The network of WSR-88D radars is the Nation's principal source of radar-derived weather data. The Next-Generation Weather Radar (NEXRAD) Program, a joint Department of Commerce, DOD, and Department of Transportation effort, acquired and deployed the WSR-88Ds to "detect wind velocity and improve detection of precipitation, severe thunderstorms, and tropical cyclones; increase weather warning lead times; enhance the safety and efficiency of the National Airspace System (NAS); and provide automated exchange of digital weather radar data" (NEXRAD MOA 2004, pg. 2). Of the 164 WSR-88D units in the national network, 120 are operated for NOAA/NWS, 26 are for DOD, 12 are for FAA, and 6 are support systems.

The FAA uses the Terminal Doppler Weather Radar (TDWR) system to detect and predict microbursts, gust fronts, wind shifts, and precipitation near airports. The FAA has 47 TDWR units: 45 operational and 2 support. Like the WSR-88D, the TDWR radar is an MRCR design.

The FAA also derives some near-airport weather data from separate weather channels on its airport surveillance radar (ASR) systems.

2.1.2 NOAA/NWS Current and Emerging Weather Radar Needs

NOAA/NWS relies on the WSR-88D network for accurate, timely, high-resolution radar data to fulfill its mission to "*provide weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy.*" NWS data and products are available through a national information database and infrastructure to other governmental agencies, the private sector, the public, and the global community. To meet its current observing and forecast responsibilities, the NWS needs radars capable of sensing hydrometeors (rain, snow, hail, etc.) and weather features permitting the detection or identification of tornadoes, tropical cyclones, precipitation rates and amounts, thunderstorms, fronts, mesoscale convective systems, and data on various wind structures and boundary conditions.

NWS objectives for improving future radar observations beyond the current capability of weather surveillance radars include increasing refresh rates, decreasing data latency, and increasing spatial resolution. Most severe weather warnings based on radar data (e.g., tornadoes, microbursts, thunderstorms) have short lead times and are usually based on near-real-time data. Phenomena such as tornado vortices are easily missed unless the spatial and temporal resolution of the radar scan can be increased to match the scale of the vortex. Minute-by-minute radar updates are needed to identify incipient tornado vortices before they touch down. The *NOAA Long-Term Research Plan for Revolutionizing Tornado Warnings* (March 2003) established an objective for future radar systems of producing a full volume scan in less than 1 minute, compared with the current capability of a full scan in 4 to 6 minutes. Achieving this objective would contribute to increasing the warning lead time for tornadoes.

NOAA/NWS hydrometeorological forecasts and warnings depend on accurate, rapidly updated radar data. Improvements beyond current weather radar capability are necessary to get better measurements of hydrometeor size and type, including distribution in both the vertical and horizontal dimensions of the scan volume. Dual-polarization Doppler radar could contribute to these objectives. Hydrometeorological data are not only the basis of nowcasts and flash flood warnings; they also feed NWP models capable of quantitative precipitation forecasting (QPF). Such forecasts are becoming an increasingly critical NWP product for applications ranging from stream flow management and agriculture to surface transportation management and urban meteorology.

Improved NWP models—those operating at storm scale and able to resolve squall lines, hurricane structure, and tornadoes—will require extremely high resolution radar data to feed their initial fields. Monostatic Doppler radars like the WSR-88D only provide radial winds. However, initialization of improved NWP models at the appropriate scale demands accurate three-dimensional vectors of wind, highly resolved and rapidly updated, from the boundary layer to an elevation of 60,000 feet.

To get the most information on rapidly developing severe weather conditions, weather radar operators must have the flexibility to interrogate weather features as situations dictate. Current weather radars are constrained to a preset menu of volume scanning options and elevation angles, limiting their operators' ability to quickly scan or adapt to changing conditions. An adaptive scanning capability would enable data to be collected intensively in certain regions of a storm (for instance, where tornadoes are likely to form) while decreasing scans of less-critical regions to periodic surveillance. Adaptive scanning thereby increases the information gathered on critical conditions in a given time interval without diminishing the capability for full surveillance coverage.

As a tropical storm or hurricane approaches a coastline, radar becomes the primary tool for estimating winds, precipitation amounts, and the likelihood of tornadoes. Hazardous weather threats, especially in the form of potential floods and tornadoes, continue for several days after a hurricane makes landfall and travels inland as a tropical storm or depression. Once the storm is over land, flash floods and wind damage, including tornadoes spawned by the interaction of the storm with terrain, typically become the principal threats to safety, essential infrastructure, and property. NOAA/NWS, the media, and private companies rely on weather surveillance radar to issue official watches and warnings and otherwise alert emergency managers, businesses, and the general public to these hazards.

2.1.3 Weather Surveillance Needs of the Department of Defense

The DOD relies on radar weather surveillance data in support of its mission to train, equip, organize, and employ military forces in the defense of the United States. The ability to access remotely, integrate, and analyze weather radar data from multiple areas of interest is a primary military need. These data are needed to support the national defense mission for two primary purposes:

- Resource protection of military assets from weather hazards; and
- Effective operational employment of military forces in all weather conditions.

Resource Protection. Multimillion dollar weapon systems, especially aircraft, are extremely susceptible to severe weather events such as hail and tornados. Weather surveillance radar provides the capability to detect these weather phenomena in time to protect systems at risk. Advance warning to guide protective actions (tying down, hangaring, or evacuation) is essential in maintaining the combat readiness of military assets. Even in clear air, weather radar can provide wind information essential for accurate atmospheric diffusion forecasts if chemical weapons are launched against U.S. forces.

Operational Employment. Many military operations are inherently weather-sensitive. Besides the inherent weather sensitivity of basic aviation, other specialized military operations (e.g., precision airdrops, aerial refueling, precision-guided munitions employment, aerial training, artillery firing, airborne gathering of intelligence) are susceptible to wind, precipitation, and reduced visibility. Timely, high-resolution radar data greatly improve the weather information needed to guide effective decisions on these and many other operations. For example, both precision airdrop and wind correction for Army artillery are greatly assisted by accurate wind profiles—data that can be provided by weather surveillance radar in clear air mode. Timely location and tracking of convective cells with radar can improve decisions on whether an air refueling track must be relocated. Concentrated precipitation reduces trafficability—the ability of terrain to support the movement of Army land forces—and accurate localized precipitation rates from weather radar can guide estimates of trafficability changes. The Army Corps of Engineers relies on accurate flood forecasts obtained from radar-derived precipitation estimates.

2.1.4 FAA Weather Surveillance Needs

Weather affects the safety of flight, the efficiency of aircraft in the NAS, and the efficiency of Air Traffic Control. Accurate, timely information regarding small-scale phenomena such as wind shear, downbursts, wake vortices, turbulence, and icing, especially in the terminal area, is essential to flight safety. En route and terminal thunderstorms must be accurately characterized to vector aircraft safely around them. By interagency agreement, NOAA/NWS provides critical en route weather data and products to the FAA. The data provided by FAA terminal-area systems, such as the TDWR, together with the en route data and products from NOAA/NWS, are critical for advising pilots of conditions and for making decisions related to traffic movement and separation.

Improved weather data, including tailored forecasts and observations, are prerequisites for the planned threefold increase in aviation capacity over the next two decades, as discussed in the *Next Generation Air Transportation System (NGATS)* integrated plan prepared by the Joint Program Development Office. The NGATS plan requires finer-resolution radar data to identify aviation weather hazards, both at terminals and en route, as capacity increases and weather impacts are magnified. Current FAA-owned weather surveillance systems are aging and are unlikely to be able to handle the NAS weather surveillance needs of 2025.

2.1.5 FHWA Weather Surveillance Needs

FHWA promotes the use of radar weather data by State, local, and commercial entities to track weather hazards to the safety and efficiency of transportation on the Nation's roads and highways. Other forms of surface transport (rail, port, inland waterway, and public transport) are also subject to weather hazards and come under the purview of other Federal entities. Although FHWA does not own or operate roadways, it provides funding to further the understanding of weather impacts on roads and to advance the effective use of weather information (both observed and forecasted) for the roadway environment. The main FHWA customers are State and local highway agencies.

A 2004 NRC study, *Where the Weather Meets the Road*, identified the following deficiencies in the current WSR-88D radar network with respect to the needs of users and managers of surface transportation systems: substantial gaps in boundary layer coverage, lack of precipitation phase discrimination, and excessive ground clutter. In response to the OFCM survey on radar needs, FHWA identified a future need for low-level radar coverage. Priority locations for such coverage include urban areas and other high-traffic zones where weather effects on surface transport are magnified. The planetary boundary layer is inadequately sampled by the current weather surveillance radar network. Current weather radars sample less than 30 percent of the lowest one kilometer of the troposphere. Intensive low-level coverage of the atmosphere is mainly confined to major airports where a TDWR has been fielded. Complex meteorological processes within the lowest few kilometers remain an observational and modeling challenge. Yet these interactions must be better known to improve forecasts of weather affecting surface transportation.

During the requirements phase of the Maintenance Decision Support System project, which is supported by FHWA's Road Weather Program, participating State departments of transportation indicated that the onset and duration of precipitation are the single most important parameters for winter road maintenance. Other parameters high on their list include type and amount of precipitation and wind character (gustiness). The State departments of transportation require finer range and azimuth resolutions than are now available, with better coverage in the lowest portion of the atmosphere. They need faster data refresh rates to capture the onset and cessation of precipitation and changes in the wind field, which are used to detect downbursts/microbursts and wind shifts in the boundary layer. They require precise information about precipitation type to determine maintenance and traffic management strategies.

2.1.6 Reliability—A Shared Requirement

Reliability is a critical requirement for all of these weather surveillance radar applications. Having a WSR-88D unit out of commission in the midst of severe weather is a dangerous situation. Any new system will be required to meet or exceed the reliability of current WSR-88D units, summarized in section 2.4. As the in-place units age, maintenance and engineering retrofits to maintain this level of reliability will become an increasing operating cost. Future reliability requirements should balance this need for continuous operation against design cost, maintenance staff cost, and the cost of maintaining sufficient spare parts on site to keep units operating.

2.2 Aircraft Surveillance Radar

The current civilian aircraft surveillance infrastructure operated by the FAA includes radar as the "primary" surveillance system and a transponder-based system as the "secondary" surveillance system.

- The "primary" surveillance uses radar to detect the radio-wave "echo" from reflection or backscatter from the surface of an aircraft. This surveillance mode is also called "skin painting" radar. Because the radar detects aircraft without any signal originating from the aircraft, it is also called "independent" or "non-cooperative" surveillance.
- The current "secondary" aircraft surveillance method is called "cooperative surveillance" because it relies on the aircraft having a transponder on board. The transponder automatically transmits information (e.g., an identification code and aircraft altitude) in response to the signal transmitted from a beacon antenna. On current FAA units, the antenna for this cooperative surveillance beacon is typically mounted on top of the rotating radar antenna used for primary surveillance.

Although the FAA has historically used a combined primary (skin-painting) radar and secondary (transponder-based) surveillance network for air traffic control, it is planning to shift to an entirely cooperative surveillance system for the NAS (see Section 2.2.4). Nevertheless, for homeland security needs and for aircraft lacking a cooperative transponder, a requirement for non-cooperative surveillance throughout the NAS will continue. Note that "non-cooperative" does not necessarily mean "hostile"; it simply means the aircraft is not announcing its position to air traffic controllers and other aircraft in the NAS by means of a transponder.

Future aircraft tracking capability must meet or exceed current refresh rates and range resolution capability. As with weather radar applications, aircraft tracking requires a highly reliable system. Future aircraft tracking systems must maintain or improve on current requirements for minimum availability of units in the system. These requirements on existing capability are included in the summary of radar performance requirements in section 2.4.

2.2.1 Current Aircraft Surveillance Radar Capabilities

Radars currently used for aircraft surveillance in the NAS include airport surveillance radar (ASR) systems and air route surveillance radar (ARSR) systems. Non-cooperative surveillance is considered the primary surveillance mode of these existing systems, whereas their cooperative surveillance capability is typically referred to as "secondary surveillance."

The ASR-9, a short-range (60 nmi) aircraft surveillance radar, is the airport surveillance radar used at 129 high-density airports. Within its coverage area, it provides non-cooperative surveillance at 10 cm wavelength and, with Mode Select, cooperative surveillance. ASR-9 has a separate weather channel with associated processing, which can provide six-level weather contours to measure the location and intensity of storms. The ASR-9 is based on 1980s technology and had an initial planned service life to 2005. A Service Life Extension Program for the ASR-9 has been initiated to ensure that essential units remain functional through 2025. Thirty-five ASR-9 units have been modified with a Weather Systems Processor, which provides automated detection and warning of low-altitude wind shear.

The ASR-11 is a digital terminal air traffic control radar that is being procured by the FAA and the Air Force Electronics Systems Center to upgrade existing radar facilities at DOD and civilian airfields. Intended for smaller airports, it is replacing ASR-7, ASR-8 and AN/GPN-12, -20, and -27 radar systems, many of which are more than 20 years old, Like the ASR-9, the ASR-11 has both non-cooperative (primary) and cooperative (secondary) surveillance subsystems. The primary surveillance radar uses a continually rotating, tower-mounted antenna with a range of 60 nmi. The monopulse secondary surveillance radar uses a second antenna attached on top of the primary antenna to transmit and receive aircraft location data (aircraft identification code, barometric altitude, and emergency conditions). Air traffic control can use the ASR-11 cooperative surveillance system to verify the location of aircraft within a 120-nmi radius of the radar site.

ARSRs are used by Air Route Traffic Control Centers to detect and display an aircraft's position while it is en route between terminal areas. ARSR-1, ARSR-2, and ARSR-3 systems were deployed across the United States in the 1960s for FAA and U.S. Air Force use. They provide non-cooperative (primary) en route aircraft surveillance to a range of 200–250 nmi. The radars operate in the L-band (30 cm wavelength), with antennas that continually rotate at 5 rpm. In general, these ARSR models do not provide aircraft altitude information from the non-cooperative signal, although variants of the ARSR-3 have been developed that provide coarse altitude information.

The ARSR-4, which was developed in the 1980s, is deployed at 40 sites around the perimeter of the United States for joint FAA and U.S. Air Force use. Like the earlier ARSR models, the primary surveillance radar transmits a 30 cm wavelength beacon. The rotating antenna uses a phased illuminating array that forms stacked receiving beams, allowing the ARSR-4 to provide aircraft altitude measurements (within the constraints of the 2-degree stacked beams).

2.2.2 DHS and DOD Homeland Security and Defense Needs

DHS coordinates with FAA and DOD in tracking and responding to non-cooperative aircraft flying within and toward U.S. airspace. Non-cooperative aircraft must be quickly located within the vast stream of cooperating aircraft and then further characterized to identify those with possibly hostile or unlawful intent. Currently this information is provided by aircraft surveillance radar systems owned and operated by FAA and covering much of the continental United States (CONUS) and U.S. territorial waters. However, there are many gaps in the coverage, particularly at low altitudes as depicted in figure 2-1.

According to DOD's *Strategy for Homeland Defense and Civil Support* (2005), "the nation will need to develop an advanced capability to replace the current generation of radars to improve tracking and identification of low-altitude airborne threats." DHS must be able to react to non-cooperative, possibly hostile aircraft operating at all altitudes over the CONUS and territorial waters.

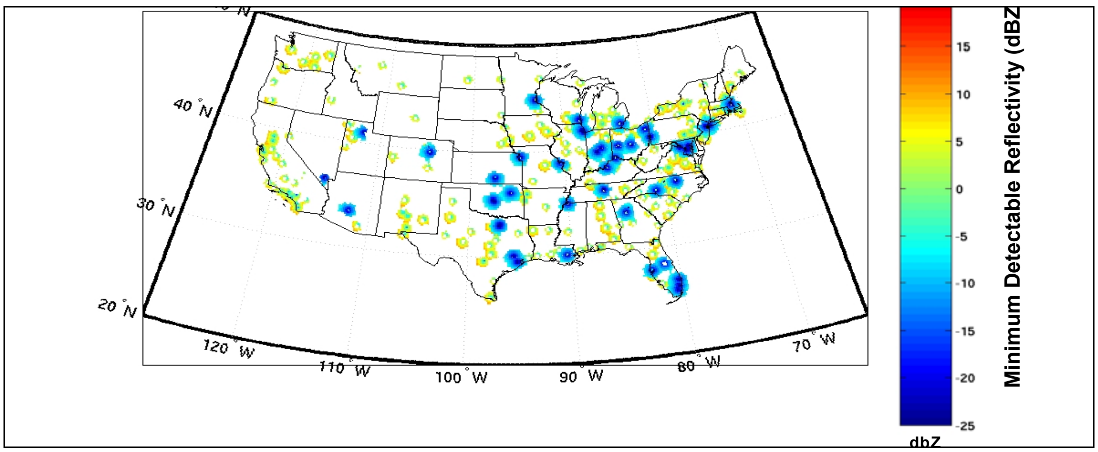

Figure 2-1. Minimal detectable reflectivity of current aircraft surveillance radar at 1000-ft. elevation.

2.2.3 FAA Requirements for Non-Cooperative Aircraft Data

Although FAA does not have primary responsibility for identification and tracking of non-cooperative aircraft, it does require real-time data on the location of non-cooperative aircraft so that air traffic controllers can deconflict cooperative aircraft flying in the same area as the non-cooperative aircraft. The concept of *domain awareness* is emerging as the complement to cooperative aircraft surveillance for the next-generation air traffic control system. The draft *Next Generation Air Surveillance Plan* (2005) requires performance improvements for sensing and tracking non-cooperative aircraft to ensure domain awareness. In general the plan demands greater vertical and horizontal coverage, increased sensitivity, finer resolution in all three dimensions, and improved data update rates.

2.2.4 Cooperative Aircraft Surveillance

Cooperative aircraft surveillance is currently provided by the same units used for non-cooperative surveillance, as a secondary surveillance mode (see section 2.2.1). For purposes of air traffic management (e.g., vectoring and separation), cooperative surveillance data are used for instantaneous location of aircraft aloft, both en route and in terminal airspace.

On a typical day, approximately 60,000 flight plans for Instrument Flight Rules flights are filed with the air traffic system, with 145,000 En Route Center Operations handled throughout the NAS. According to the *Next Generation Air Transportation System (NGATS) Integrated Plan*, the number of passengers supported may range from 2 million per day to 4 to 5 million per day by the year 2025. It is clear from the NGATS plan that the current system cannot handle future aviation system needs. To fulfill the NGATS goal, the FAA must accurately track all aircraft (cooperative or otherwise) in an environment of increasingly high traffic density and reduced standard intervals for separation and sequencing. The combination of aging FAA radars and the projected higher demand on an already burdened air traffic system drives the need for a more capable, highly reliable tracking system. Enhanced cooperative surveillance technology (e.g., ADS-B) backed up by a cost-effective national MPAR network is a promising approach for meeting this need.

2.3 Other Surveillance Functions Performable by Radar

While the preceding sections summarize the major radar applications for weather and aircraft surveillance by Federal agencies and the constituencies they serve, there are a multitude of other users with diverse needs that are currently being met or could be met with a nation-wide network of surveillance radars. Among the non-Federal users are State and local governmental entities, public-private partnerships, commercial enterprises, and the academic research community. Other Federal agencies known to use information derived from the NEXRAD weather surveillance network include DOE (weather data to support predictions of consumer energy use), the Department of Agriculture (rainfall data), and the National Park Service and National Interagency Fire Center of the Department of the Interior. A sample of the diverse current and potential applications for radar is presented below.

2.3.1 Airborne Releases of Toxic Materials

DHS and State and local emergency preparedness agencies must be able to quickly identify airborne releases of toxic chemical, biological, or radioactive agents, and then track the plume of the hazardous material as it travels by atmospheric transport and diffusion. In sufficient volume density, airborne release of hazardous materials can be detected directly by radar. In all cases, accurate and real-time data on local winds, particularly within the planetary boundary layer, are crucial for tracking the plume and predicting, with the aid of ATD models, where it will travel and what the risk level is for any location downwind. Current temporal and spatial resolution of wind data is inadequate for this purpose, as is the skill in forecasting plume movement and concentration. The recent OFCM report, *Federal Research and Development Needs and Priorities for Atmospheric Transport and Diffusion Modeling* has identified the need for sufficiently high resolution data to allow modeling at the microscale/urban scale (OFCM 2004). Radar can provide the needed measurements. Federal agencies with responsibility for monitoring or responding to airborne releases of toxic agents include DHS, DOD, DOE, Nuclear Regulatory Commission, EPA, and NOAA/NWS.

2.3.2 Weather Surveillance in Support of Spaceflight Operations

Flight operations where details of localized downrange atmospheric conditions can be critical, as in NASA space launches and vehicle reentry and landing, can be made safer by a capability to dwell on a spatial volume of high interest, such as a front or cell that could produce sudden turbulence. Radars currently used for atmospheric research do this; the application is established. However, for a single-beam radar unit, dwelling on high-interest features must be balanced against the primary continuous-scan function of weather surveillance.

2.3.3 Calibration and Validation of Satellite-Based Remote-Sensing Instruments

NASA, NOAA, and several DOD services and agencies (Navy, Air Force, and others) continue to plan, develop, and launch satellites carrying new generations of remote-sensing instruments, such as radiometers. To use the data from these instruments to derive information on atmospheric conditions, the instrument must be calibrated against a "ground truth" source of information about the atmospheric parameters of interest. In addition, the information derived from the remote observations must be periodically validated against ground truth. For many atmospheric conditions, land-based radar provides the volumetric measurements needed to establish ground truth for these satellite-based instruments. Thus, the land-based weather surveillance network is an integral part of achieving National and international goals set for the Global Earth Observation System of Systems (GEOSS).

2.3.4 Fire Weather and Wildland Fires

Radar has much to offer to the fire weather community. In addition to detecting and tracking airborne aerosols such as smoke, radar can track in real time the fine-scale changes in wind field due to terrain-atmosphere interactions and the influence of the fire itself on local wind and weather conditions. Radar can be used to track the smoke plume and estimate air quality in the vicinity and downwind of wildland fires. Rainfall can assist in controlling and possibly extinguishing a fire, and radar is invaluable in locating precipitation that may affect burning or endangered areas and determining its intensity. Convective cells can also produce wind shifts that cause the fire line to change direction. These direction changes can pose threats to firefighters, people who were formerly in safe zones, and property. Radar indications of thunderstorms and associated lightning over areas with high-risk levels of dry fuels can give indication of where new fires may ignite.

Federal agencies that need improved fire weather information include the Department of the Interior (U.S. Park Service, Bureau of Land Management, Fish and Wildlife Service, U.S. Geological Survey), Department of Agriculture (U.S. Forest Service), DHS (FEMA and the U.S. Fire Administration), EPA, the Department of Health and Human Services (Centers for Disease Control and Prevention), and NASA. Beyond these Federal users, State and local fire hazard management and fire control agencies down to the level of volunteer fire departments need the timely fire weather information that radar can provide.

2.3.5 Debris Flows (Mudslides)

Many emerging, specialized applications for radar use information from a known radar phenomenon but apply it for an innovative purpose. The emergence of weather surveillance radar from early aircraft surveillance applications is an historical example. New applications of radar are emerging now that use weather surveillance radar data. For example, radar information on precipitation intensity and duration at a specific location is now being used to estimate the total precipitation falling on hillsides prone to debris flows (e.g., mudslides).

Accurate rainfall amount is a key piece of information for the debris-flow warning system because even small amounts of precipitation beyond ground saturation can trigger strong flash floods and debris flows. Rain gauges are relatively sparsely located on such slopes, and convective cells often produce intense rainfall amounts over very small areas, which may not contain a rain gauge. The debris-flow models being developed and applied by the U.S. Geological Survey require high-resolution precipitation data, such as QPF and near-real time precipitation rates from observations. Radar provides the only available tool to continuously monitor the spatial distribution of precipitation at horizontal scales small enough to link convective downpours to specific terrain at risk. Radar-derived precipitation amounts are compared to thresholds for debris flow derived from hydrologic models based on historical data. The thresholds for debris flow for a given canyon, for example, are based on a combination of rain intensity and duration—data that can be provided continuously by radar. Localized rainfall estimates for this and other applications, such flash floods in hilly terrain and field-specific agricultural management, will improve as dual-polarization weather surveillance radar systems are implemented.

2.3.6 Air Quality and Health

More accurate routine monitoring and prediction of air quality at regional and intra-urban scales depends on the same degree of knowledge of local wind fields required for the emergency response to a point release of an airborne hazardous material. Air quality warnings and assessments use diagnostic and predictive models of atmospheric constituents of concern, but the models depend on accurate observations, at the required spatial and temporal scales, of the wind field within the planetary boundary layer, precipitation, and other atmospheric parameters that can be measured with advanced radar techniques. Monitoring air quality is a responsibility of EPA, the Centers for Disease Control and Prevention, and NOAA/NWS.

2.3.7 Volcanic Ash

Airborne volcanic ash is a hazard to aviation and, in sufficient density, to surface transportation. It can cause public safety and health problems. Since the ash can be carried aloft as high as the tropopause, volcanic ash plumes need to be detected quickly and then tracked from surface elevations to a height of 50,000 ft. Radar sensing of volcanic ash plumes can augment satellite observations.

2.3.8 Birds as an Aviation Hazard

Bird strikes pose a severe hazard to aviation, particularly when birds are flying in large flocks. The ability to identify and track bird flocks in flight will be a continuing need for aviation safety. Dense flocks of birds produce radar signatures, even with the current weather surveillance and aircraft surveillance radars. Dual-polarized radars are capable of distinguishing bird radar signatures unambiguously from those of aircraft or meteorological phenomena.

2.3.9 Agricultural Applications of Radar Data

The agriculture industry and family farms use radar-based products and services to time the application of insecticide and fungicides to crops. Radar-derived precipitation estimates and short-range forecasts are used to set irrigation strategies and crop spraying schedules. The Department of Agriculture is also very interested in, and uses, hail data (swath coverage), high-resolution reliable storm rainfall estimates (especially over data-sparse areas), and surface-adjusted wind vectors and peak surface winds.

The WSR-88D radar has been used to track insect swarms that travel with the winds for hundreds of miles. The low-level jet in the Great Plains is remarkably efficient in transporting insects from south to north in the early morning hours. These pests are harmful by themselves, but they also carry molds and fungi (Wolf et al. 1995).[1]

2.4 Summary of Radar Performance Needs

The questionnaire sent to Federal users of radar data asked respondents about the performance needs for their existing applications or envisioned for future radar applications essential to Agency missions and responsibilities. Common themes among the responses are summarized below and in tables 2-1 and 2-2.

- **Resolution**. Spatial resolution (beam width, horizontal and vertical) and temporal resolution (scan rate) of radar must increase to match the scale of the phenomena of interest. This applies to both weather and aircraft surveillance.

[1] In addition to the report by Wolf et al. (1995), summaries of the use of NEXRAD to track insect crop pests can be found in research reports at the website of the North Central Regional Committee on Migration and Dispersal of Biota. See, for example, research summary on "Mid-season Insect Migration" by John Westbrook, Texas A&M Univ., and "Ground-truth of NEXRAD Doppler Radar Measurements" by Wayne Wolf, Texas A&M University, at http://www.inhs.uiuc.edu/cee/movement/more_res.html.

Table 2-1. Needs Summary Table—Weather Surveillance

Parameter	Current Capability	Future Need
Derived weather phenomena	Instantaneous rain rate, snow, hail, icing, turbulence, winds, microbursts, wind shear, tornado vortex signature	All of current plus clouds (bases and tops), aerosols (concentration and size distribution), and lightning.
Vertical Coverage	From 1 km to 70,000 ft.[a]	From surface to 70,000 ft.
Horizontal Coverage	US states and territories, and surrounding water/borders[b]	Same as current
Range Resolution	250 m (for Doppler moments); 1 km for reflectivity moments	Less than 100 m
Sensitivity	From -20 to 5 dBZ	At least as sensitive as current
Scanning Mode	Clear air and severe weather volume coverage patterns; constantly increasing elevations for one complete volume scan	Optimize scanning to better cover the lowest 3 km, using negative angles if necessary
Reliability	96% (WSR-88D)	At least as reliable as current capability
Data Latency	Less than 4 minutes (data latency is determined by fact that entire WSR-88D volume scan must be completed before data becomes available)	Less than 10 seconds
Update Rate	4–6 minutes for a full volume scan (reflectivity versus clear air)	1 minute or less
Dual Polarization	Planned for deployment on WSR-88D	Should be included in any new system
Radars Networked?	Yes[c]	Yes

[a] More than 70 percent of the lowest 1km of atmosphere is unsampled by WSR-88D.

[b] DOD requires tactical radars for global deployment.

[c] WSR-88D reflectivity products are mosaicked; future need is for radar data from multiple sources that can be automatically fused into single operational pictures in near-real time

- **Coverage.** Near-surface coverage with minimized clutter is needed. Blind spots widen with increasing distance between radars; mountains exacerbate blockage. Technology must be developed to fill these gaps in coverage.
- **Integration.** Individual radar units must be connected in an integrated network. Information from multiple units in a radar network must be fused automatically into a single coherent four-dimensional view that is easily displayed to and understood by users and decision-makers.

Table 2-2. Needs Summary Table—Aircraft Surveillance

Parameter	Current Capability	Future Need
Derived aircraft parameters	Aircraft position	Aircraft position, speed, direction, elevation, and type
Vertical Coverage	From 1 km to 60,000 ft.[a]	From surface to 100,000 ft.
Horizontal Coverage	All U.S. states and territories, including surrounding waters and borders.[b]	Same. Perimeter extends 600 nmi beyond border/coast
Range Resolution	1/8 nmi (1/16 nmi at airports)	Less than 1/8 nmi.
Sensitivity	2.2 m^2 cross-section (probability of detection >80%)	0.1 m^2 cross-section; targets separated by <0.125 nmi reported as separate targets
Scanning Strategy	Repeated base scans every minute; fixed surveillance mode does not allow interrogation of individual objects	Optimize scanning to better cover the lowest 3 km, using negative angles if necessary; agile scanning to interrogate individual objects
Data Latency	120 seconds	<2 seconds
Update Rate	10–12 seconds en route; 4–5 seconds near terminal	<5 seconds
Reliability	99%	At least as reliable as present units
Dual Polarization	Not available	Should be included in any new system
Radars Networked?	Yes[c]	Yes. Data available in common, interoperable formats.

[a] Lowest 1 km of atmosphere is unsampled by aircraft surveillance radars over 70% of CONUS.
[b] DOD requires air traffic control radars for global deployment.
[c] The minimal need is for aircraft surveillance radar data readily shared among FAA, DOD, and DHS.

- **Scanning Agility.** Capability is needed for intensive interrogation of a phenomenon of priority interest, while maintaining surveillance of the remainder of the sky. With respect to requirements for intensive focus and sustained breadth of surveillance, the need is typically for both capabilities at once, not a choice between one or the other.
- **Data Assimilation.** Weather radar data must be readily assimilated into NWP models, including mesoscale models. As an NRC committee has stated, "Currently radar is the only observing system with the potential of providing initial conditions for very high-resolution numerical weather prediction models" (NRC 2002).
- **Reliability.** High levels of reliability, including rapid repair/replace maintenance capabilities, are essential for weather surveillance and aircraft surveillance applications. Future radar units and networks must be at least as reliable as current operational radars for these critical applications.

The user needs listed in tables 2-1 and 2-2 are effectively performance requirements on future observing systems. They derive from the responses received to the OFCM questionnaire. Future weather and aircraft surveillance radar units and networks should be able to meet these needs.

In summary, future radar technology must improve upon inherent limitations of present radars for both aircraft surveillance and weather surveillance tasks. The parameters where improvement is needed include low-level coverage, multifunction capability, agile scanning, higher refresh rates, increased spatial resolution, and improved reliability.