NOAA Weather Radar Strategy

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NWS-OAR Retreat

Background

- Based on the 2008 NOAA Weather Radar 20-Year Vision Report, produced by the NOAA Joint Radar Planning Team (Co-led by Kevin Kelleher of NSSL and Daniel Melendez of OST, with team members from NWS/OST, OOS, OCWWS, OAR/NSSL, ESRL, and OFCM)

Radar Improvement Drivers

- Improve severe weather warning services performance
  - Tornado warning performance has been stagnant at 14-min average lead time, with only ~50% detection of non-zero lead time, and stubborn 75% false alarm rate
  - NWS stretch goal is probabilistic high-resolution tornado warnings with 60-min lead time, and greatly reduced deterministic false alarm rate (50%)
- Address meso-scale, including storm scale observation gaps to provide necessary data assimilation into NWP models for warn-on-forecast
  - Geographical coverage in inter-mountain west and costal areas
  - Boundary layer coverage (<2km from ground level) and adequate spatial resolution
  - Improved temporal resolution to capture the rapid evolution of strong convective storms

High Level Radar Strategy

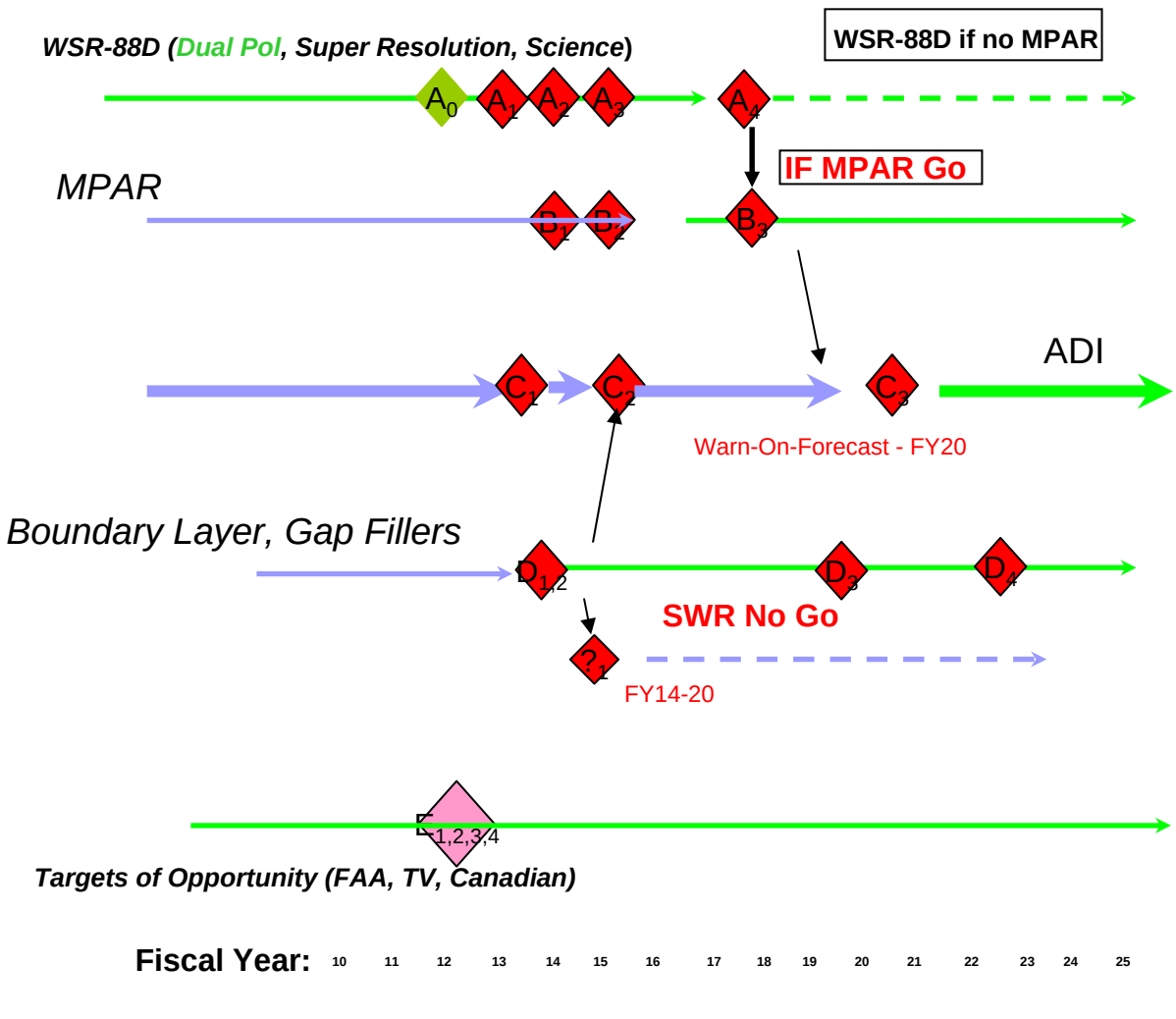
- Sustain/Improve WSR-88D capabilities through at least 2020, and until replacement technology is determined
  - Signal processing techniques to improve data and reduce update times
  - Improve scientific algorithms for better products on tornado detection, QPE, initiation of convection, etc.
  - Hardware technology refresh and evolution, including signal processors, pedestals, scientific workstations, routers, etc.
- Incorporate data from non-NOAA radars
  - Current systems: FAA terminal and en route, Canadian, private sector, etc.
  - Future systems: FAA terminal MPAR or other replacement systems, CASA-type radars, etc.

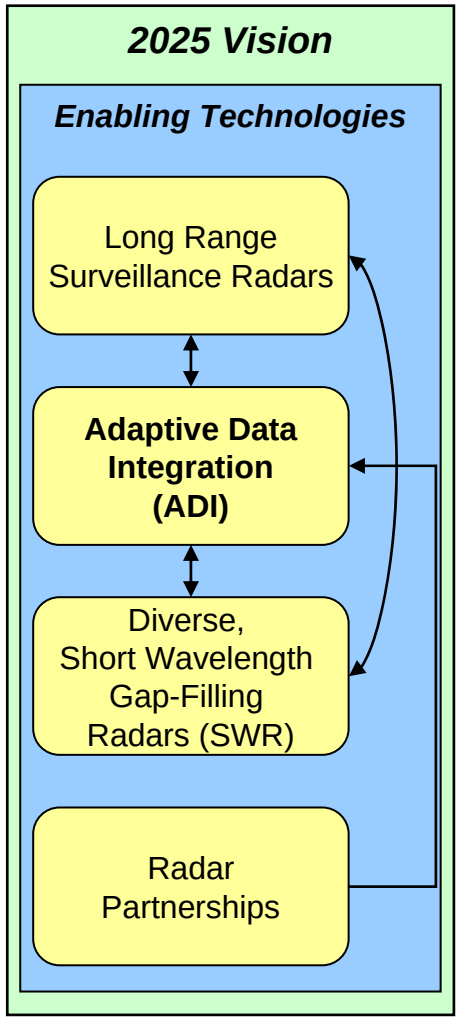
High Level Radar Strategy (Continued)

- Foster advances in use of radar data in integrated observational data fusion (multiple radars, mesonet, upper air, satellite, etc.) and in adaptive storm scale data assimilation to reduce NWP variances
  - *Adaptive data integration*
- Define and document mission data requirements, observation gaps, testing and evaluation (T&E) process, use to evaluate emerging radar technologies
- Evaluate emerging radar technologies: conduct cost-benefit analysis, T&E using radar testbed (OAR, CASA, etc.), and system optimization to recommend optimal mix of observational systems for the future
  - Major WSR-88D hardware refresh (e.g., improved pedestals)
  - Replace and/or augment WSR-88D with MPAR, CASA-type systems (short-wavelength networks), or other commercial technology (hybrid digital array/conventional radars)

20-Year Radar Roadmap

NOAA Radar Roadmap - Decisions



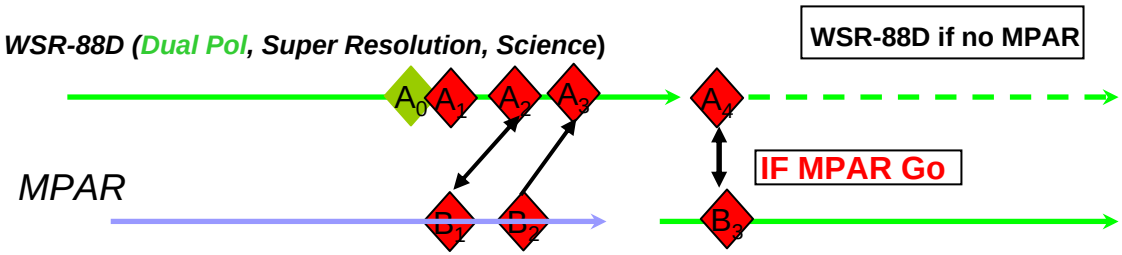


Fiscal Year: 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

R&D

Acquisition /Deploy

20-Year Radar Roadmap (cont.)



WSR88D/NPI

‡A0: FY12 – Complete dual polarization implementation – CONTRACTED.

A1: FY13 -- NPI zero-funding

A2: FY14 – FAA ASR8/9/11 replacement decision

A3: FY15 (soft) – WSR-88D life extension decision; MPAR maturity

A4: FY18 –Evaluate WSR88D in light of FAA and MPAR progress

MPAR

B1: FY14 - FAA ASR replacement decision

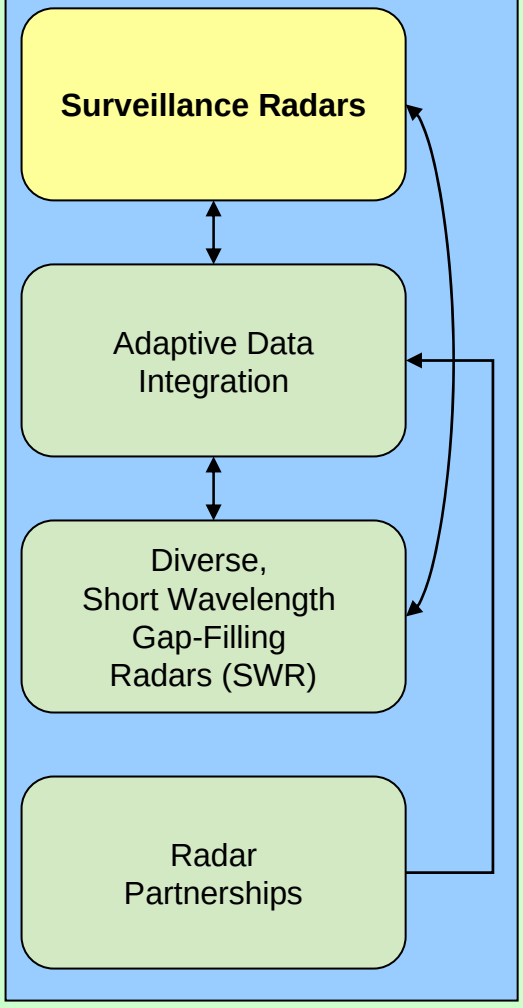
B2: FY15 – MPAR maturity: design dual-pol capability; complete digital receivers; multi-panel design completion

B3: FY18 – MPAR Go/No Go decision for FAA partners (drives Cost Benefit analysis). Begin prototype acquisition process. Has the technology proven itself?

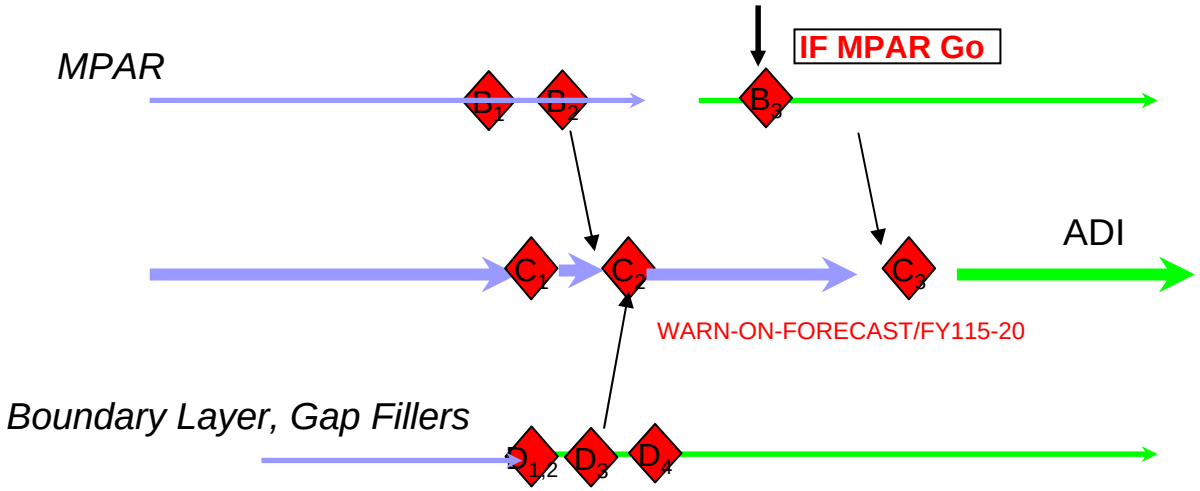
Note: In 2002 the NAS-NRC recommended pursuit of PAR technologies for replacement of WSR88D.

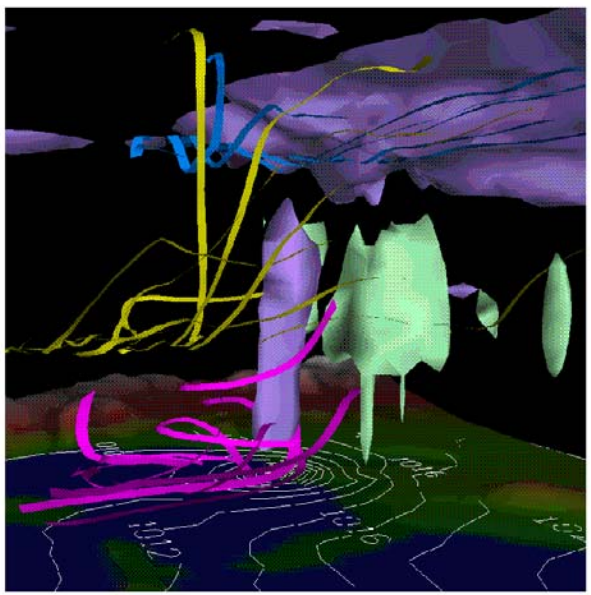
2025 Vision

Enabling Technologies



20-Year Radar Roadmap (cont.)





ADI

C_1: FY14 – Adaptive Scanning

C_2: FY15 – Start Warn on Forecast

C_3: FY20 – Adaptive "Closed loop" intelligent data integration

2025 Vision

Enabling Technologies

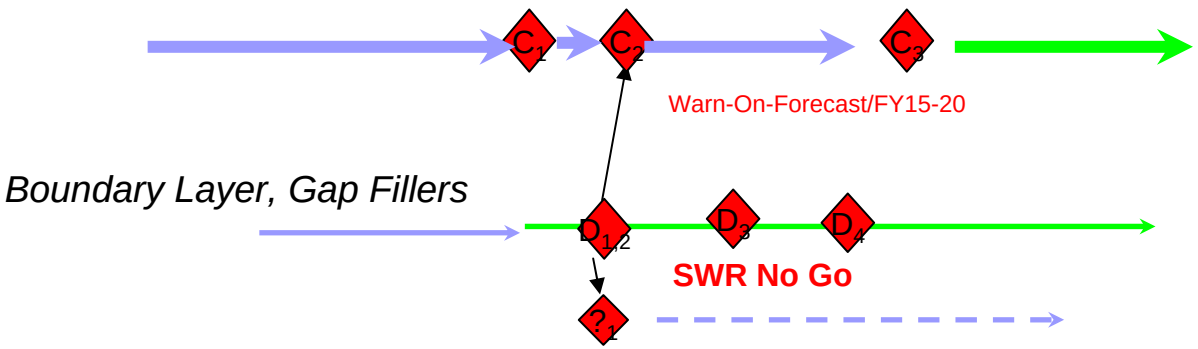
Surveillance Radars

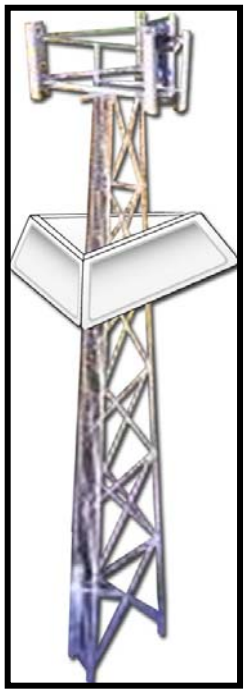
Adaptive Data Integration (ADI)

Diverse, Short Wavelength Gap-Filling Radars (SWR)

Radar Partnerships

20-Year Radar Roadmap (cont.)





SWR

D1: FY14 – End of NSF funding of CASA. Does NOAA support post-CASA "Entity" implementation?

D2: FY14 – CASA & SWR QPE/F Testbed Go/No Go

D3: FY20 – NOAA SWR Prototype Acquisition Go/NoGo

D4: FY23 (soft) – SWR Deployment

?1: FY14-20: Unspecified boundary layer sensor alternatives (surface nets? UAS?)

2025 Vision

Enabling Technologies

Surveillance Radars

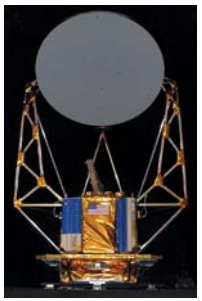
Adaptive Data Integration

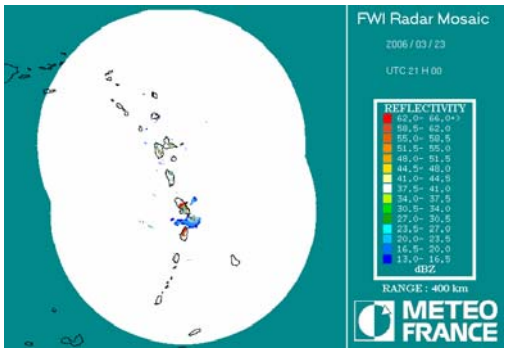
Diverse, Short Wavelength Gap-Filling Radars (SWR)

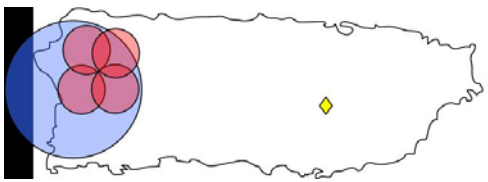
Radar Partnerships

20-Year Radar Roadmap (cont.)

Targets of Opportunity (FAA, TV, Canadian)







Targets of Opportunity

E_1: FY12 - FAA Radars

E_2: FY12 - Canadian Radars

E_3: FY14 - Private-sector & Caribbean radars

2025 Vision

Enabling Technologies

Surveillance Radars

Adaptive Data Integration

Diverse, Gap-Filling Radars

Radar Partnerships

Recommendations

- Approve the 20-Year Joint Radar Plan as a joint formal NWS-OAR planning document
- Charter a NOAA Joint Radar Planning Project/Committee to
  - Integrate and coordinate planning, evaluation and assessment of ground weather radar science and technology advancements that can improve NWS operational performance
  - Provide advice and consultation to NOAA senior leadership on radar related science, technology and strategies, and recommend options at key decision points.
  - Update Joint OAR-NWS Radar Plan and provide radar program guidance to PPBES and similar activities. Need to build a business case to continue funding of weather radar science (NPI, OAR) in order to satisfy 2025 Vision
- Develop strategy to overcome the budget challenge due to NPI termination in FY13, and to ensure critical R2O transfer and technology refresh are accomplished to improve radar performance and services

BACKUP SLIDES

Performance Measures: Severe Weather Program

Proposed	Current (2009)	FY 2016 Target Example	FY 2025 Target Example
Tornado Warning Lead Time	14 min (SBW)	20 mim	1 hour
POD	72% (SBW)	80%	90%
FAR	74% (SBW)	65%	50%
Severe Thunderstorm Lead Time	17 min (SBW)	23 min	1 hour
POD	77% (SBW)	85%	95%
FAR	44% (SBW)	35%	20%
Statistical Reliability	Not currently Measured	Better than climatology	Better than baseline
Flash Flood Lead Time	66 min (SBW) 77 min (county)	1 hr	4 hours
POD	79% (SBW) 91% (county)	85% (SBW) 91% (county)	90%
FAR	43% (SBW) 58% (county)	40% (SBW) 40% (county)	30%
Probabilistic Reliability		Better than climatology	Better than baseline
Convective Initiation lead time	Not currently measured	10 min	60 minutes
POD	Not currently measured	Better than climatology	50%
FAR	Not currently measured	Better than climatology	50%
Statistical Reliability	Not currently measured	Better than climatology	Better than baseline

SBW = Storm-based warning

Alternatives and Contingencies

- What if MPAR prototype does not meet NWS performance requirements?
  - Continue operating and upgrading WSR-88D
  - Partner with other potentially beneficial technology development
  - Ingest FAA digital array weather radar data (ASR/ARSR/TDWR replacements)
  - Supplement with short-wavelength adaptive digital/phased array radar network data
- What if short-wavelength phased array radars are too expensive?
  - Buy data services from external organization
  - Consider buying conventional short-wavelength antenna
  - Deploy dense meso- and micronets to enhance coverage
  - Investigate weather performance of broad beamwidth short-range dual-polarized low-power radars (e.g., marine-class radar) for operational applications such as QPE and filling gaps

1.) Executive Summary

- The nation's weather analysis, forecasting and warning services need to be improved
  - 50% of tornados occur without advance warning
  - 75% of tornado warnings are false alarms
  - Many areas lack quality observational data for stratiform rain, snow, freezing rain, convective initiation mechanisms such as wind boundaries, low level convective storms, etc.
- Similarly, other NOAA/NWS services impacting the safety and efficiency (aviation, marine, fire weather, etc) in operations also need to be improved
- Weather radar is a prime observational tool for all such services, and is anticipated to remain so for the foreseeable future given its superior cost effectiveness
- Existing NOAA/NWS radars are continually being enhanced through the NEXRAD Product Improvement program (NPI) both technologically & scientifically
- Data from other existing radars (FAA, Canadian, private sector) can be brought into NOAA/NWS operations
- Impressive new radar technology is being developed to utilize digital phased array and multifrequency antennas to improve data timeliness, spatial resolution and areal coverage
- Dramatic mission performance improvements are foreseen with better radar observations and numerical modeling applications
- Planned R&D efforts and Science-to-Operations activities not funded in current budget

1.) Weather Radar Role

- Weather Features Observable by Radar – Convective Storms
  - Tornado potential analysis
    - Tornadic scale circulation patterns
    - Mesocyclones (broader scale circulation patterns associated with many tornadoes)
    - Storm relative helicity (ambient environment wind flow relative to motion of storm)
    - Vertical wind profile at the radar site (analysis of vertical shear)
    - Tornadic storm morphology (e.g., hook echoes)
  - Severe thunderstorm potential analysis
    - Storm tops & Vertically Integrated Liquid Water (indicators of storm updraft strength)
    - Hail indications from dual polarization
    - Rapidly descending storm cores (downbursts and microbursts)
    - Bow echoes (associated with severe straight line winds)
  - Flash flood potential analysis
    - Rainfall rates (derived from reflectivity, including polarimetric variables)
    - High spatial resolution rainfall accumulation estimates
  - General thunderstorm activity
    - Convective initiation from convergence boundaries (e.g., storm outflows, sea/lake breezes)
    - Storm tracking and future position forecasts

1.) Weather Radar Role (cont.)

- Weather Features Observable by Radar – General
  - Areas of rain, both stratiform and convective
  - Storm tracking and future position forecasting
  - Pre-storm environment
    - Vertical wind profiles
    - Low level moisture (water vapor from refractivity measurements)
- Weather Features Observable by Radar – Hurricanes
  - Three dimensional wind field
  - Storm tracking
  - Tornadic scale circulation patterns in outer bands
  - Tornadic storm morphology (e.g., hook echoes)
  - Rainfall rates (derived from reflectivity, including dual polarization variables)
  - High spatial and temporal resolution rainfall accumulation estimates
- Weather Features Observable by Radar – Winter Weather
  - Rain-Snow line, with dual polarization
  - Freezing rain areas, with dual polarization combined with surface temperatures
  - Snowfall rates and accumulation
  - Height of freezing level (to help analyze areas of potential aircraft icing)

2.) Mission/Vision

Mission Mandates

NOAA/NWS Mandates for warning and forecast services include:

- U.S. Code Title 15 Chapter 9 for warning and forecast services – Directs National Weather Service to forecast the weather, issue storm warnings, etc.
- Public Law 107-253 for inland flood forecasts and warnings – Authorizes NOAA to improve forecast and warning capabilities.
- Department of Homeland Security's National Response Plan, December 2004, uses the foundation provided by the Homeland Security Act, HSPD-5 and the Stafford Act to provide an all hazard approach to incident management. It tasks the Department of Commerce and NOAA with acquiring and disseminating weather data, forecasts, and emergency information.
- BLM Interagency Agreement identifies NWS as official source of meteorological information

2.) Mission/Vision

NOAA Strategic Planning & Vision

NOAA 2006-2011 Strategic Plan

- NOAA Goals:
  - Serve society's needs for weather and water information
  - Support the Nation's commerce with information for safe, efficient and environmentally sound transportation
- Weather & Water Mission Goals:
  - Reduced loss of life, injury, and damage to the economy.
  - Better, quicker, and more trusted weather and water information to support informed decisions.
  - Increased satisfaction with quality of weather and water information and services.

NOAA 20-year Research Vision for 2025

- Tornado warning lead times will be on the order of one hour, rather than minutes.
- Technology like phased array radar, significant improvements in our understanding of mesoscale weather processes and the development of models that embody this understanding will enable this accomplishment.
  - Today's 'Warn on Observation' warnings will be enhanced by 'Warn on Forecast' based on models
- New tools, technologies and procedures will enhance safety & capacity in air traffic management practices.

2.) Mission/Vision

Mission Services Impacted By Radar

NOAA/NWS warning and forecast services impacted by radar data include:

- Severe convective weather (tornadoes, strong thunderstorms, large hail)
- Floods and flash floods
- Hurricanes and associated weather
- Winter weather
- Aviation weather
- Marine weather
- Drought and water management information
- Non-severe thunderstorms, rainfall, winds, etc.

2.) Mission/Vision

NOAA/NWS 20-year Performance Vision Impacted by Radar

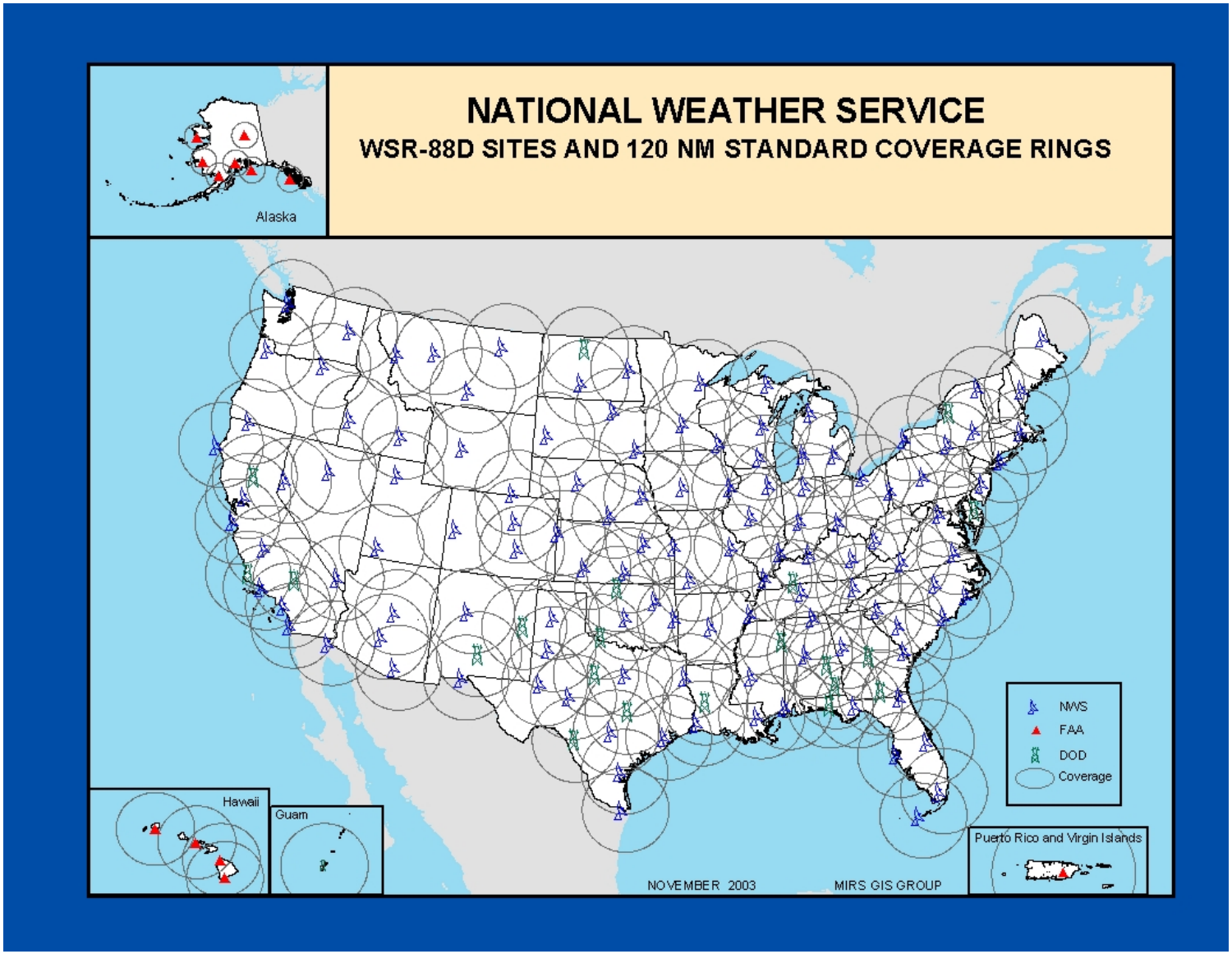
- High Impact Weather
  - Neighborhood-scale warnings
  - 45 min to an hour tornado warning lead times
  - 3 hour flash flood warning lead times
  - Hurricane landfall and inundation detailed information improvements
- Drought and Water Resources
  - Improved rainfall and snowfall accumulation and forecast information
    - Four-fold estimation accuracy
    - Spatial resolution and geographical coverage
- Aviation, Marine and Public
  - Highly accurate, multi-hour forecasts of convective systems

3.) Societal Impacts

- NOAA 2006-2011 Strategic Plan
  - Floods, droughts, hurricanes, tornadoes, tsunamis, wildfires, and other severe weather events cause $11 billion in damages each year in the United States. Weather is directly linked to public health and safety, and nearly one-third of the U.S. economy (about $3 trillion) is sensitive to weather and climate.
  - At least $4 billion is lost annually due to economic inefficiencies resulting from weather-related air-traffic delays.
  - Improved surface weather forecasts and specific user warnings would reduce the 7,000 weather related fatalities and 800,000 injuries that occur annually from crashes on roads and highways (with an annual average related cost of $42 billion).
- Anticipated impacts of NOAA/NWS mission performance improvements:
  - Lives saved and property damage reduced through improved warnings
  - Aviation efficiency and safety
    - Improved terminal and en-route observations and forecasts
    - Improved hail, turbulence, freezing rain and in-flight icing information
  - Surface transportation efficiency and safety
    - Improved winter weather and heavy rain observations and forecasts
  - Weather-impacted commercial activity efficiency and safety
  - Improved data/forecasts leveraged by commercial weather services
  - General public quality of life and daily activities planning

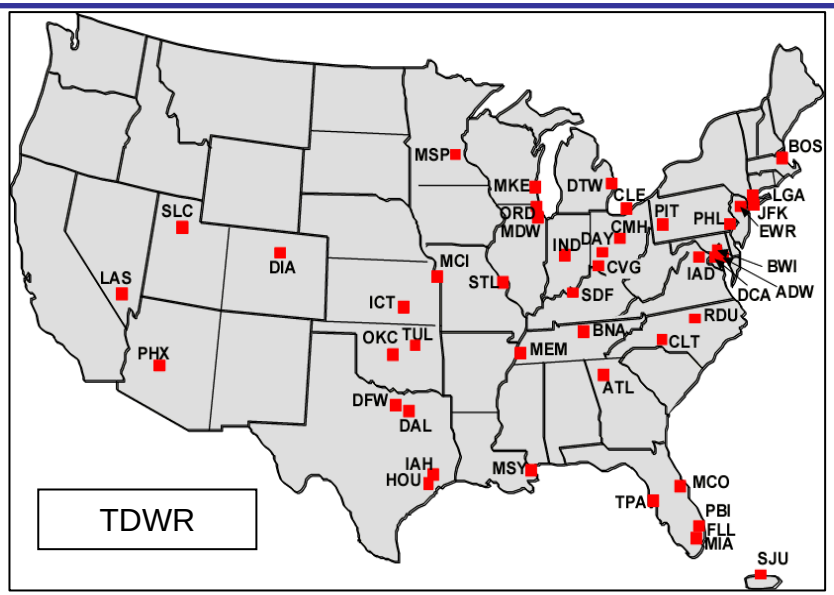
4.) Existing Capabilities

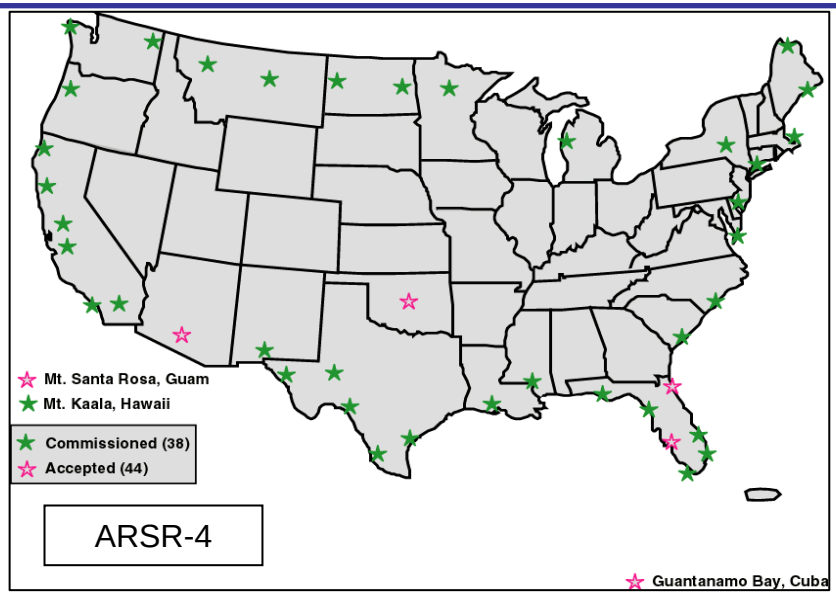
WSR-88D Network Coverage

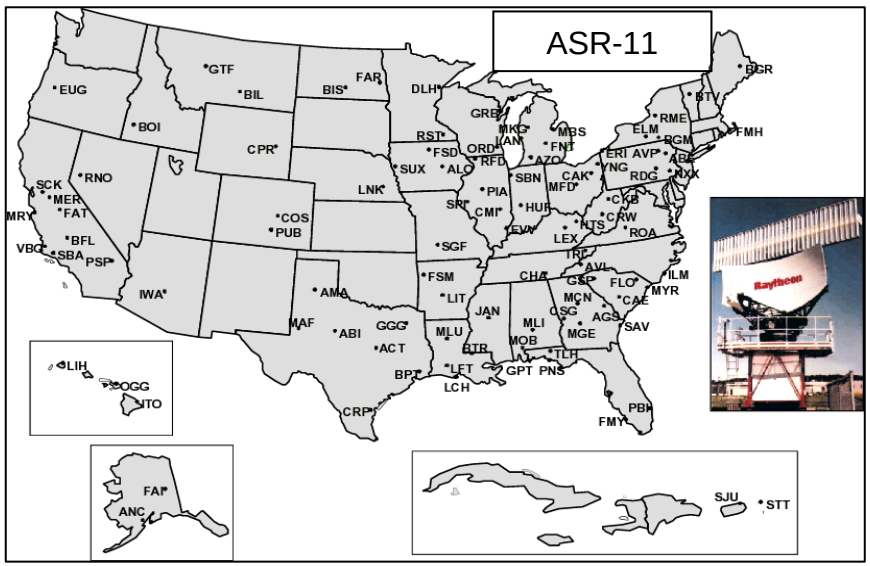


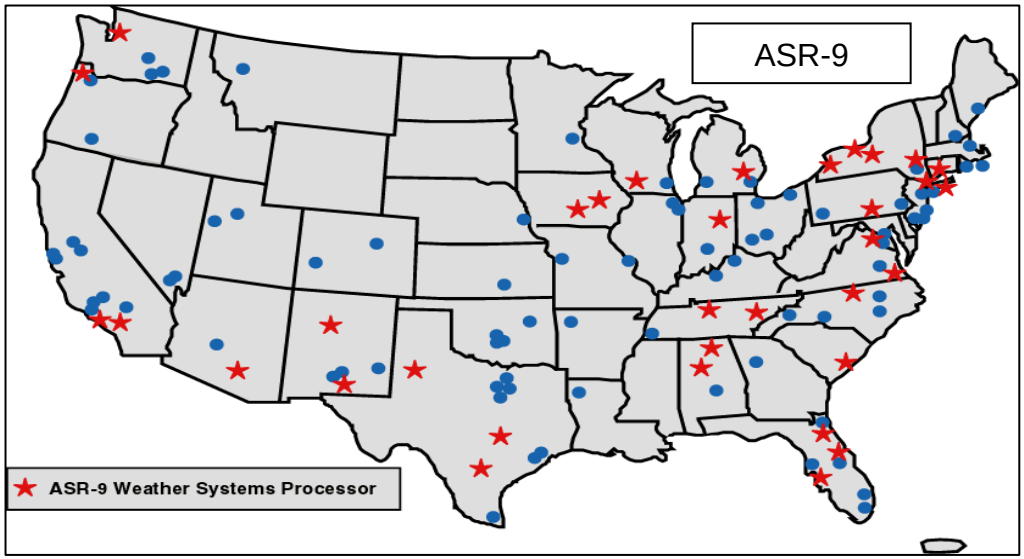
4.) Existing Capabilities

FAA Network Coverage





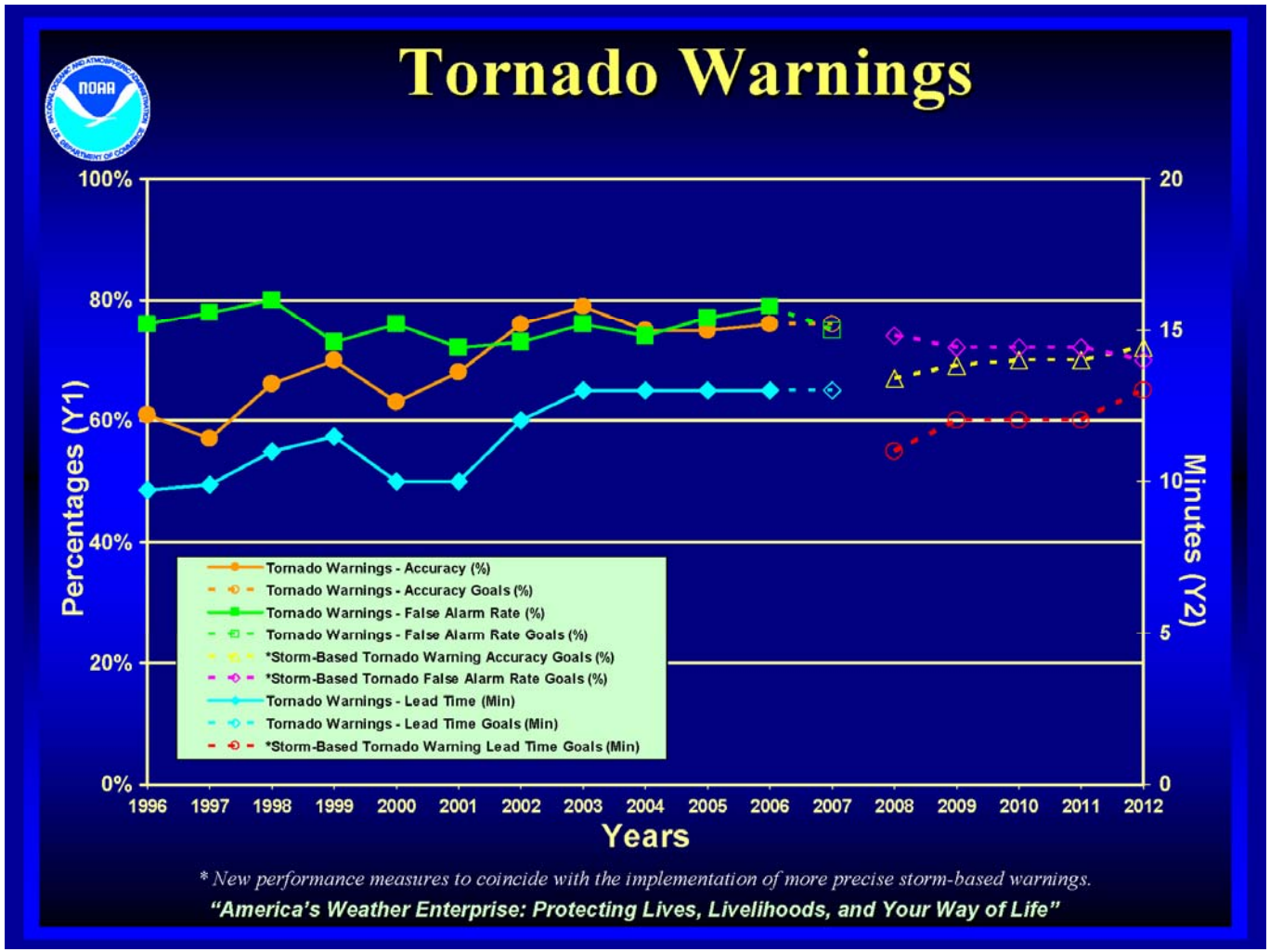




4.) Existing Capabilities

Tornado Warnings

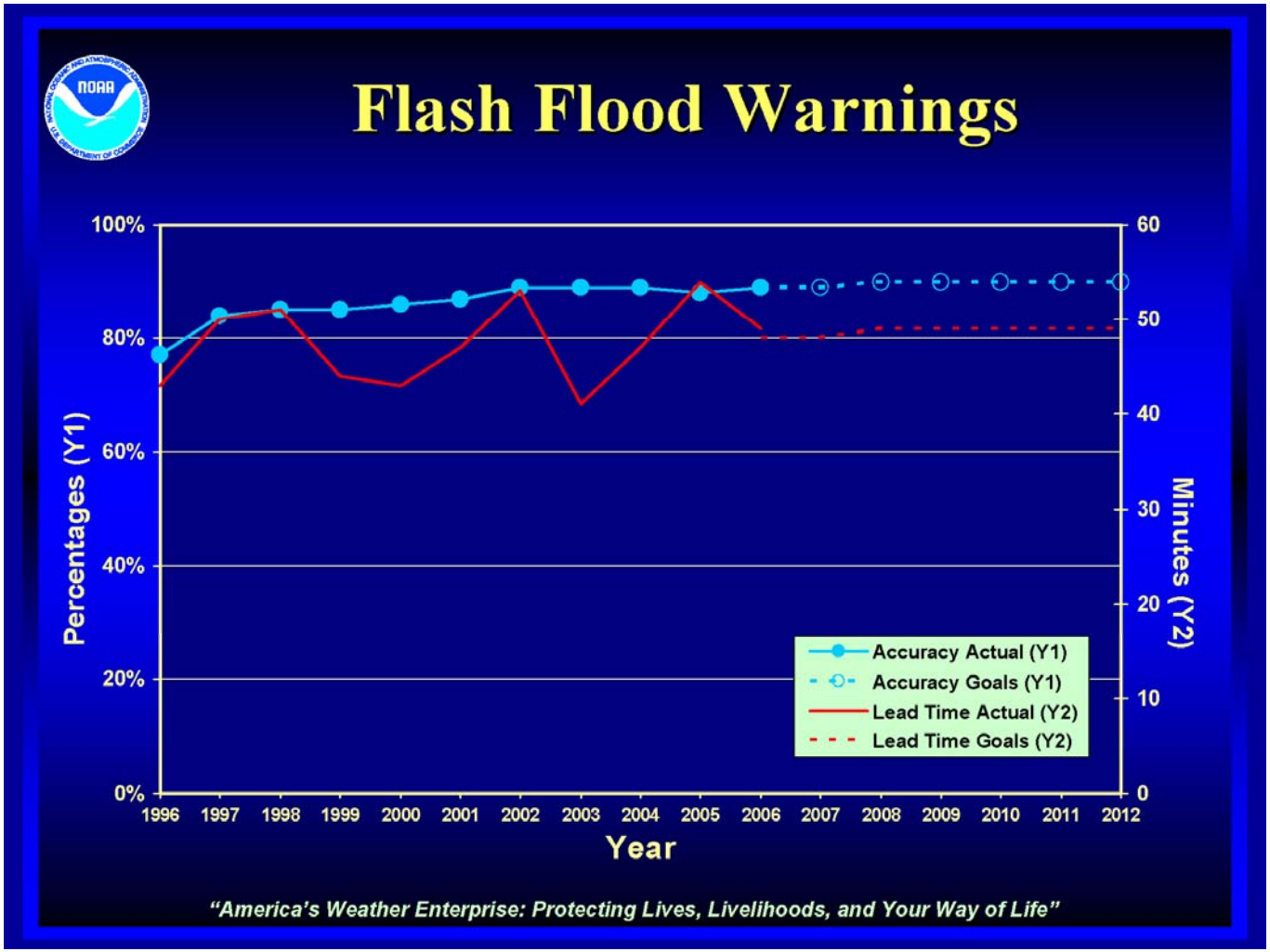
Tornado warning performance has leveled off, and, with existing science and technology, is not projected to improve.



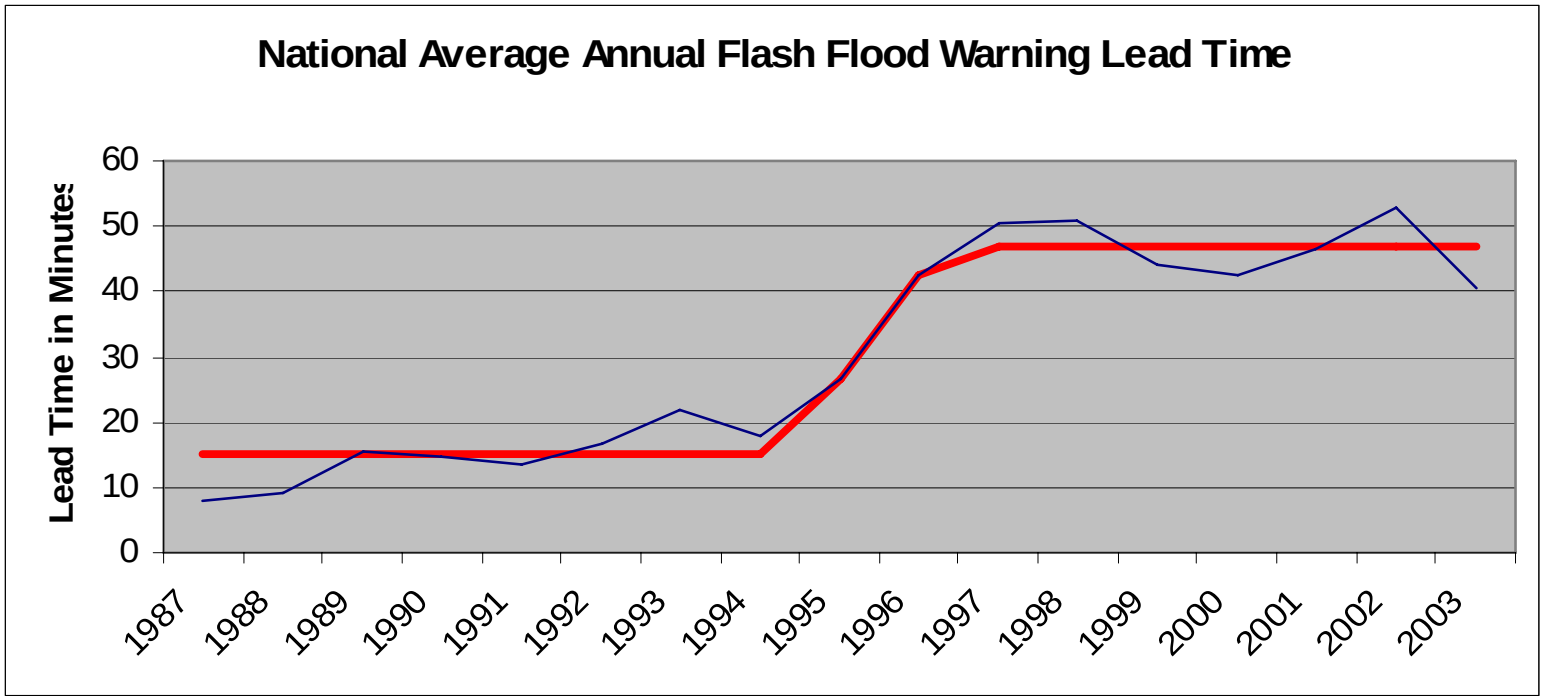
4.) Existing Capabilities

Flash Flood Warnings

Flash Flood warning performance has leveled off, and, with existing science and technology, is not projected to improve.



Impact of Radar on Flash Flood Services



NEXRAD Implementation

5.) Performance/Vision Gaps

Performance Gaps

- 50% of tornados occur without advance warning
- 75% of tornado warnings are false alarms
- Many tornado, severe thunderstorm and flash flood watches and warnings lack small scale areal resolution

Data Gaps

- While tornadic storm development and significant evolution can occur in a minute or less, low altitude WSR-88D observations of such storms are updated only every 4-6 min.
- At longer ranges and in complex mountainous terrain, the WSR-88D beam height and/or blockage degrade detection of shallow precipitation and convective initiation precursors such as dry lines and converging wind boundaries.
- 72% of the atmosphere below 1 km is not observed by the WSR-88D network

R&D Gaps

- Current NOAA budget profiles do not fund the level of radar hydrometeorological R&D necessary for informed programmatic decisions on whether to acquire MPAR or CASA-like radars
- Storm scale numerical data assimilation and modeling do not support ‘warn on forecast’ operations

Research to Operations Gaps

- Current NOAA/NWS budget profiles do not fund the infrastructure necessary for robust R-to-O
  - Prototyping of proposed operational algorithms by R&D groups, as directed and monitored by NWS
  - Structured implementation of approved algorithms for integration into WSR-88D operational baseline

6.) ‘Blue Ribbon’ Recommendations

- **(2002) National Research Council Report: Weather Radar Technology Beyond NEXRAD**
  - The potential value and technology to incorporate data from complementary radar systems to provide a more comprehensive description of the atmosphere should be investigated.
  - Adaptive waveform selection, which may even be applied to present systems, and agile beam scanning strategies, which require an electronically scanned phased array system, should be explored to optimize performance in diverse weather.
  - The technical characteristics, design, and costs of phased array radar systems that would provide the needed rapid scanning, while preserving important capabilities such as polarization diversity, should be established.
  - The potential for a network of short-range radar systems to provide enhanced near-surface coverage and supplement (or perhaps replace) a NEXRAD-like network of primary radar installations should be evaluated thoroughly.
- **(2002) NWS Tornado Warning Improvement Team**
  - Integration of FAA radar data; Increased spatial & temporal data density; Improved data assimilation/analysis
  - Evolution of existing radar systems
  - Phased array radar
  - Focus on numerical data assimilation and local/regional storm-scale models
- **(2004) National Research Council Report: Flash Flood Forecasting Over Complex Terrain**
  - To extend radar coverage, all available regional real-time weather radar data should be made accessible to the NWS WFOs, including Federal Aviation Administration (FAA) and Department of Defense (DoD) NEXRAD radars; FAA Terminal Doppler Weather Radars (TDWRs) and other surveillance radar equipped to provide weather-echo data; local television station Doppler radars; and operational radars from other organizations.
  - The NWS should consider augmenting the NEXRAD network with additional short-range radars to improve observation of low-level meteorological phenomena.

7.) Proposed Capability Enhancements

Multi-mission Phased Array Radars (MPAR)

Conduct the science and engineering R&D necessary to evaluate the cost-benefit of an MPAR acquisition to replace the WSR-88D

- The WSR-88D and the FAA's TDWR are aging systems, with no replacement technology yet identified.
- PAR technology offers the promise of a revolutionary improvement in weather detection, with volume updates of a minute or less, concurrent sampling of the entire vertical structure of a storm, storm-focused detailed scanning concurrent with entire umbrella surveillance, and rectilinear wind field measurement as opposed to radial velocity.
- Although the FAA is committed to an R&D program to develop a prototype PAR capability for aircraft tracking to replace its surveillance radars, NOAA must conduct scientific R&D with PAR technology to ensure that weather detection requirements are properly defined for such prototypes.
- NOAA participation in a multi-agency, multi-mission PAR development and acquisition program is crucial to deriving a realistic cost-benefit ratio for replacing the aging WSR-88D technology with PAR.
- Without PAR as a potential replacement technology, NOAA is committing to an indefinite service life extension for the WSR-88D.

7.) Proposed Capability Enhancements

Multi-mission Phased Array Radars (MPAR)

Combined FAA/NOAA MPAR economic benefits (OFCM Report R25-2006)

- 35% reduction in weather and aircraft tracking radar units versus today's total
- Estimated savings of $1.8B in acquisition costs if replacing all existing radars with similar technology
- Estimated savings of $3.0B in life cycle costs over 30 years due to fewer radars
- Reduction in number of short range radar units needed to cover gaps in low altitude coverage
  - High quality weather data from all FAA units to supplement WSR-88D coverage
  - Gaps still persisting below lowest beam at longer MPAR ranges, and in complex, mountainous terrain

7.) Proposed Capability Enhancements

Short Range, Boundary Layer, Gap Filling Radars (CASA-like)

Conduct the science and engineering R&D necessary to evaluate the cost-benefit of an acquisition to complement the NOAA surveillance radar network (WSR-88D now, potentially MPAR in the future) with low cost, short range, short wavelength radars for boundary layer and complex terrain coverage.

- The WSR-88D network coverage is excellent for detecting most mature thunderstorms and other precipitation with significant vertical development.
- At longer ranges and in complex mountainous terrain, the WSR-88D beam is too high (or is beam blocked) to detect shallower precipitation and convective initiation precursors such as dry lines and gust front boundaries.
- The Collaborative Adaptive Sensing of the Atmosphere (CASA) program, led by the University of Massachusetts, has been funded by the National Science Foundation as an Engineering Resource Center to develop low cost radars to provide reliable detection of low altitude severe weather, rain/snow, and pre-storm environment.
- For low altitude radar coverage gaps, CASA offers the promise of affordable radar deployments with improved storm detection capabilities similar to MPAR.
- Opportunities to develop NOAA operational cost-benefit ratios for CASA technology
  - The CASA operated Severe Weather Test Bed in Oklahoma
  - The NOAA Hydrometeorological Test Bed in the American River Basin in California (HMT West)

7.) Proposed Capability Enhancements

Existing Radars

Enhance temporal/spatial resolution and low level coverage with existing radars

- NEXRAD: WSR-88D
  - Add Dual Polarization capability
  - Develop and implement signal processing techniques to reduce volume scanning times and increase data accuracy
  - Develop and implement algorithms to utilize Dual Polarization data and the increased spatial detail of Super Resolution data
  - Include Super Resolution and Dual Polarization base data in Level II distribution
- FAA, Canadian and private sector radars
  - Implement data connections to all such radars that could provide significant supplemental geographical coverage to the WSR-88D network, or could provide valuable backup capability during WSR-88D outages
  - Develop and implement algorithms to utilize external radar data
  - Distribute non-proprietary base data and products to NWS, private sector and other users in standard WSR-88D Level II and Level III formats
- Research-to-Operations
  - Ensure a funding profile to continue the effective NEXRAD Product Improvement program for:
    - Managing technology implementations such as Dual Polarization
    - Prioritizing and Implementing new scientific algorithms and working with the ROC for their integration into operations