9A.14 SHIPBOARD WEATHER RADAR SENSING: CURRENT AND PLANNED CAPABILITIES

Timothy Maese*
Basic Commerce and Industries, Moorestown, NJ

Thomas McNellis
Lockheed Martin, Moorestown, NJ

Lee Wagner
SPAWAR Systems Center, San Diego, CA

Scott Sandgathe
Applied Physics Laboratory, University of Washington

Randall Case and Kim Koehler
US Navy PMW-120, San Diego, CA

1. INTRODUCTION

In the late 1990's, the US Navy conducted experiments to validate the use of shipboard air surveillance radars as weather radars. The first experiment used the SPY-1B/D radar and proved, through a series of land-based and at-sea demonstrations, that a naval radar could make meaningful measurements of atmospheric conditions as an adjunct process to the radar's normal tactical mission. The Tactical Environmental Processor (TEP), the prototype adjunct SPY-1 weather processor, first went to sea in 1999 onboard the USS OKANE (DDG77) and subsequently on the USS NORMANDY (CG60). Since then, additional experiments were conducted with the SPS-48E radar, most recently culminating with a successful demonstration of the Hazardous Weather Detection and Display Capability (HWDDC) on board the USS PELELIU in April 2006. A second installation and sea trial is planned for the USS GEORGE WASHINGTON (CVN73) in November 2007.

As these prototype systems transition to the fleet, HWDDC and TEP will be standardized around a common architecture and processing suite based on commercial technology and open-architecture software that can be inserted into the next generation of radar signal processors. A set of basic weather radar products and data formats is being generated to provide a complete array of weather data to users onboard the ship, as well as users within the battlegroup and ashore. This paper will describe the latest approach for weather product generation and dissemination for the TEP and HWDDC systems, and show the roadmap for transitioning these technologies to the fleet.

2. 'THROUGH-THE-SENSOR' WEATHER RADAR SURVEILLANCE

Dedicated weather radars are routinely found near airports around the world, and data from these radars are used by pilots and air traffic controllers for route planning. US Navy ships at sea do not have the luxury of a dedicated weather radar system on their already crowded decks, and they have gone without organic radar capabilities for decades. However, many of the existing air-surveillance radars used on modern warships perform well as meteorological radars, proven in several 'through-the-sensor' data collection experiments and demonstrations.

The key benefit of using an existing sensor to provide weather radar data is that the need to develop a new system, install it on a crowded top-side antenna mast, and perform maintenance on additional mechanical and electronic equipment is reduced significantly, if not eliminated entirely. This 'through-the-sensor', or TTS, data collection concept allows the SPY-1B/D and SPS-48E radars to provide weather data while completing its tactical mission without compromise. Through-the-sensor weather surveillance was first demonstrated and validated for shipboard radars

---

* *Corresponding author address*: Timothy Maese, BCI, Inc., Moorestown, NJ 08057; email: tmaese@bcisse.com

using the SPY-1 radar in 1999 (Maese *et al*., 2001). Although the SPY-1 is a multi-purpose tactical radar, it has several qualities that make it attractive for weather surveillance, and many of these qualities are also shared by the SPS-48E. Both systems are high power, S-band (~3GHz) rapid scanning radars, which make them ideal for detecting weather as well as penetrating heavy precipitation to provide longer range precipitation detection (unlike other bands, such as X-band, which are highly attenuated through heavy precipitation and thus are more useful for short range weather surveillance). Both radars also provide waveforms suitable for velocity processing – in tactical radars, multiple-pulse Moving Target Indicator (MTI) waveforms are used to remove clutter (sea surface returns, land returns, weather, etc.) from the radar picture where in weather surveillance processing these waveforms are ideal for providing the velocity of such clutter. In addition, the use of wider bandwidth waveforms than most traditional weather radars and faster scanning rates allow the data from the tactical systems to be averaged over range, frequency, and temporal scanning to provide acceptable measurement accuracy with a reduced number of pulses transmitted at each beam position.

An important requirement of through-the-sensor data collection is that the tactical sensor must not be changed or impede its mission in order to gather routine weather data. The tactical radar's mission is to detect and track air and surface targets, and this mission is vital to the safety of the crew and ship. Interruption of a search scan or a change to operating parameters could compromise the radar's ability to detect and track potentially hostile targets and in turn, reduce the ship's ability to protect itself from enemy weapons.

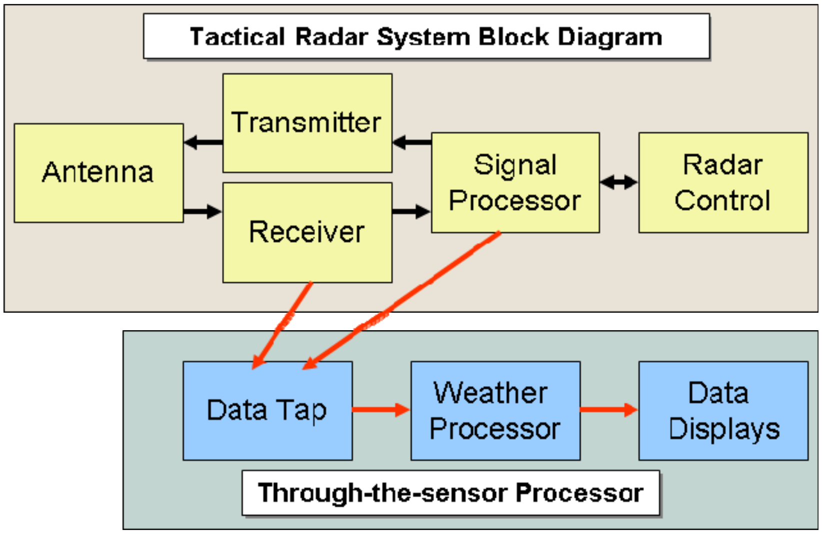


Figure 1: 'Through-the-sensor' Parallel Data Processing Concept

Therefore, the 'through-the-sensor' processing system must, at a minimum, operate using the tactical configuration of the radar, providing weather information with radar scans and parameters (such as pulsewidth, pulse repetition interval, etc.) that were developed to meet a military mission, not a meteorological mission. This challenge imposes some limitations on the data products and the quality of the products developed. However, careful selection of the target radar and processing approach can provide excellent meteorological data with no impact on the radar's tactical mission.

Once the weather data are collected, the final challenge is to distribute and present the data to the appropriate users on-board and off-board the ship in an easily interpreted format. Many Navy ships at sea do not have trained meteorologists onboard, and even those that do (such as the aircraft carriers) have many users onboard that would use the weather radar information but do not posses specific training in meteorology. Thus, data quality control and presentation of products becomes increasingly critical – as the system provides no benefit to the warfighter if the warfighter cannot understand the data quickly and effortlessly.

2.1 *SPY-1 and SPS-48E Weather Surveillance Systems*

The original prototype SPY-1 (TEP) and SPS-48E (HWDDC) weather processing systems share little in common other than the processing concepts. The prototype TEP system was built upon VME-based processors which were state of the art in 1998. The recent HWDDC system uses commercial PC servers to provide similar processing capability in a much smaller and less expensive unit, driven primarily by the explosion in technology fueling the commercial computer industry. The current implementations of both systems will be driven by a common set of hardware and modular software processing algorithms, with some customization necessary to integrate each system with the unique interfaces and capabilities of the individual radars. There are currently two approaches for integrating weather processing into each radar system; a back-fit processing capability intended to augment existing ship's with a weather capability and a forward-looking insertion into modernization of each radar's signal processor.

The back-fit option for both radars will allow for more rapid availability of weather processing capabilities to the fleet. The current architecture proposed for the SPY-1 and SPS-48E implementations uses a common hardware processor (based on the current HWDDC processor) and custom radar data interfaces for each radar. The software processing routines are modular in nature and can be reused from one system to the other. The software interfaces for the radar data taps will be custom to each radar. It is expected that approximately 75% of the software will be common, modular components with the remaining 25% custom to the particular radar interface. An intermediate data format will be created that will be common across the radars to allow for modular components to be used in the weather signal processing stages. In addition, the web-based display system developed for the HWDDC program will be used across both radar systems to provide commonality in visualizing and accessing the data products. While the SPS-48E variant is essentially in its final stage of development, the SPY-1 variant requires approximately 12 months of R&D, namely in the development of a non-interfering data tap to the radar and software modifications to the SPS-48E weather processor for use with the SPY-1 radar.

The SPY-1B/D radars are planned to be modernized with the addition of a Multi-mission Signal Processor (MMSP), an Open Architecture commercial hardware signal processor in which the weather processing algorithms can be inserted as additional software routines. Similarly, the SPS-48E radar is currently being upgraded to the SPS-48G configuration, which will replace, among other components, the signal processor and receiver hardware with modern commercial hardware. The advantage of this approach versus the backfit approach is that additional hardware external to the radar signal processor is avoided and the entire implementation is done in software. The primary disadvantage of this implementation approach is that the capability is tied to the development schedule of the new radar processors, and currently is forecasted for initial ship availability in 2012 or beyond. Table 1 summarizes the approach and availability of these four options.

Table 1: Weather Radar Processing Implementation Approach and Availability

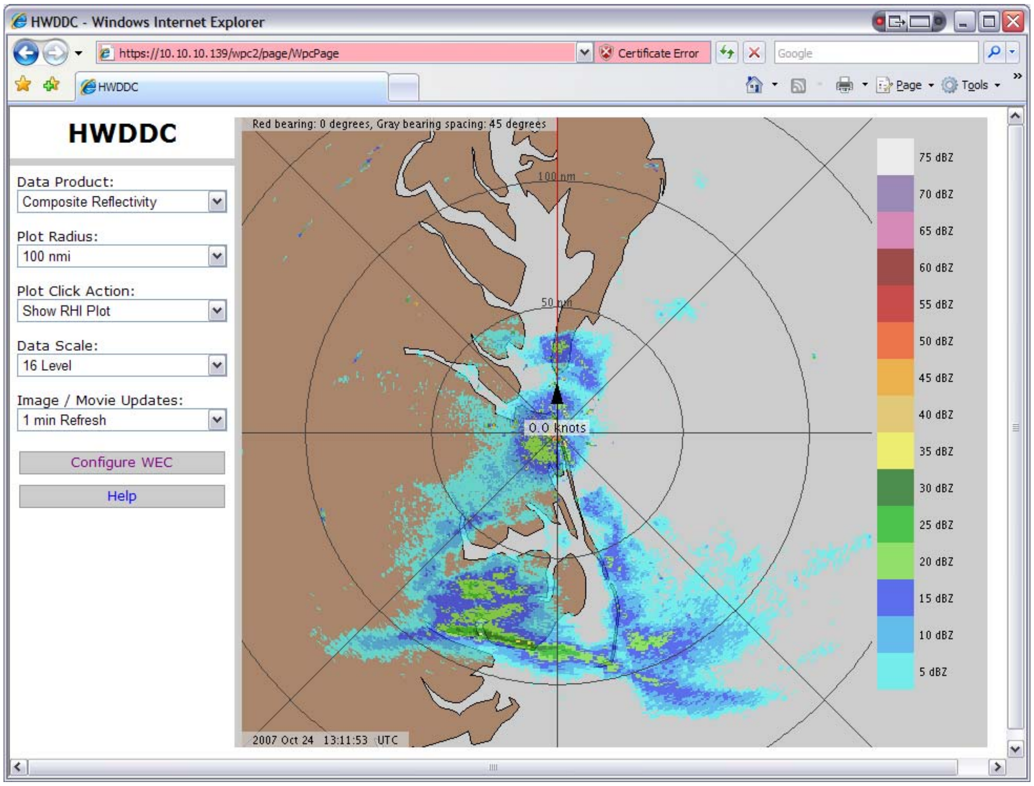
Radar	Implementation Approach	Expected Availability
SPS-48E	Backfit data tap and processor	Now
SPS-48G	Software insertion into 48G signal processor	2012+
SPY-1B/D/D(v)	Backfit data tap and processor	2009
SPY-1D(mod)	Software insertion into MMSP	2012+

Since the SPS-48E/G and SPY-1 weather systems will be based off common modular weather processing algorithms, and will have similar data product and display capabilities. Essentially, they are no longer two separate systems but one common set of processing applied to two different radars. The differences in capabilities supported by the systems are driven by the differences in the radars themselves. For instance, SPS-48E Low-Elevation scan generates velocity-producing MTI dwells that cover a fixed elevation coverage range, whereas SPY-1 MTI dwells are generated (normally) in areas dictated by the radar control loop. The maximum ranges of the products listed in the table above are based on the particular radar’s operating characteristics. The following table summarizes the data product capabilities for each radar based on the characteristics of the radar.

Table 2: Current and Planned SPY-1 and SPS-48 Weather Data Products

Attribute		System Capability	
		SPS-48E/G	**SPY-1B/D/D(V)**
Weather Data Products	Composite Reflectivity	Yes, to 125+ nm in all radar modes	Yes, to 125+ nm in all radar modes
	Base Reflectivity	Yes, to 125+ nm in all radar modes	Yes, to 125+ nm in all radar modes
	Base Radial Velocity	Yes, to 40 nm (max), all azimuths, first 3 elevations in Low-E mode only	Yes, to 64 nm (max) Coverage and range dependent on MTI scheduling
	Base Spectrum Width	Yes, to 40 nm (max), all azimuths, first 3 elevations in Low-E mode only	Yes, to 64 nm (max) Coverage and range dependent on MTI scheduling
	VAD Vertical Wind Profiles	Yes, in Low-E mode only, max. altitude ~8kft	Yes, Product generation and max. altitude dependent on MTI scheduling
	Echo Tops	Planned (algorithm being developed under ONR SBIR), all radar modes	Planned (algorithm being developed under ONR SBIR), all radar modes
	Vertically Integrated Liquid	Planned (algorithm being developed under ONR SBIR), all radar modes	Planned (algorithm being developed under ONR SBIR), all radar modes
	Storm Tracking	Planned (supported by ONR SBIR) using NCAR TITAN (1-2 hours), all radar modes	Planned (supported by ONR SBIR) using NCAR TITAN (1-2 hours), all radar modes
Sensor Optimization / Tactical Information	Refractivity From Clutter	Feasible – has not been examined and will require some development	Yes (validated for evap. and surface based ducts)
	Clutter Mapping	Yes	Yes
Weather Displays (web-service)	Planned Position Indicator	Yes	Will leverage HWDDC displays
	Movie Loops	Yes (120 minute, 60 minute, 30 minute)	Will leverage HWDDC displays
	Range Height Indicator	Yes	Will leverage HWDDC displays
	Wind Profiles	Yes	Will leverage HWDDC displays
Tactical Displays / Overlays	CCTV / CIC Video Displays	Yes	Yes
	RDCF (SPS-48G)	Not planned	N/A
	ADS (AEGIS)	N/A	Not planned
Model Assimilation		Mesoscale Data	Mesoscale Data
Model Verification		Mesoscale Data	Mesoscale Data

The common weather display is based on the web-based service developed for the SPS-48E HWDDC effort. This web display allows full access to visualize all of the weather products developed by the system via SIPRNET through a standard web-browser. There is no software requirements for the users terminal, since all displays are created on the weather processor server. Dissemination via SIPRNET allows users onboard the ship and within the battlegroup access in realtime to the weather data. Researches and forecasters located remotely can also access data files via the ship's SIPR connection, although bandwidth limitations off of the ship will likely limit access of data files (aside from the web-display) for the time being. Examples of the displays created by the HWDDC server with data captured from the SPS-48E radar in Dam Neck, VA are shown in the following figures.



Data Product: Composite Reflectivity

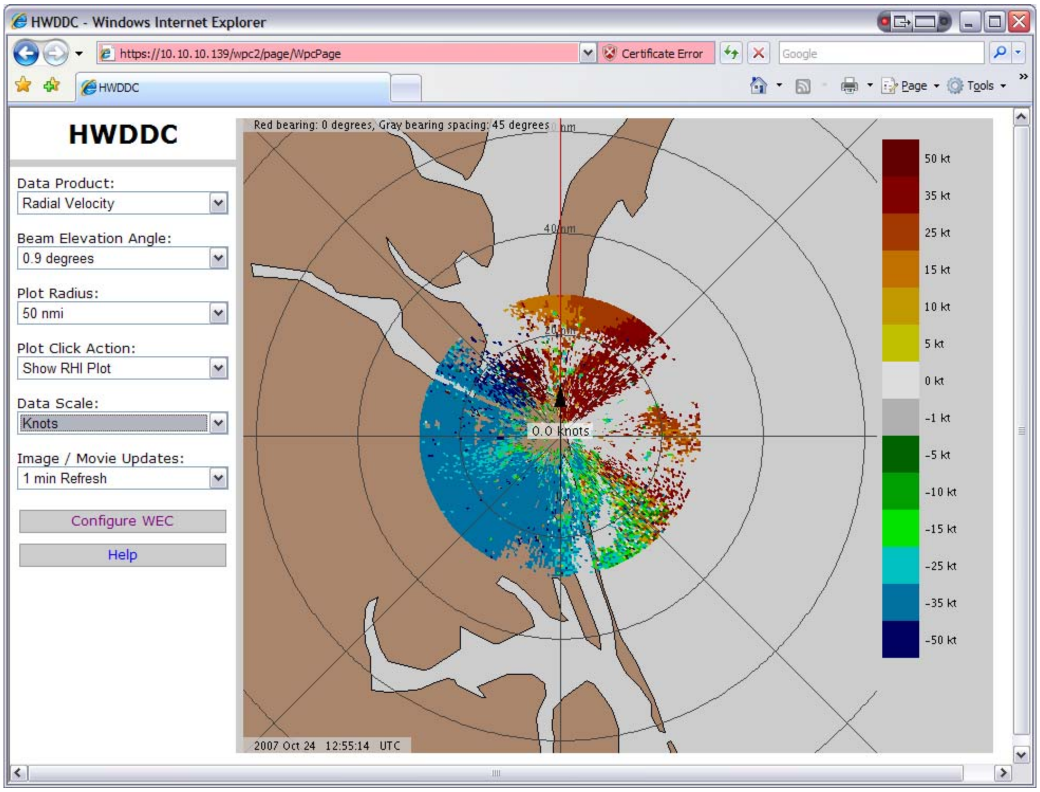
Plot Radius: 100 nmi

Plot Click Action: Show RHI Plot

Data Scale: 16 Level

Image / Movie Updates: 1 min Refresh

Figure 2: Composite Reflectivity Display from SPS-48E HWDDC System at Dam Neck, VA



Data Product: Radial Velocity

Beam Elevation Angle: 0.9 degrees

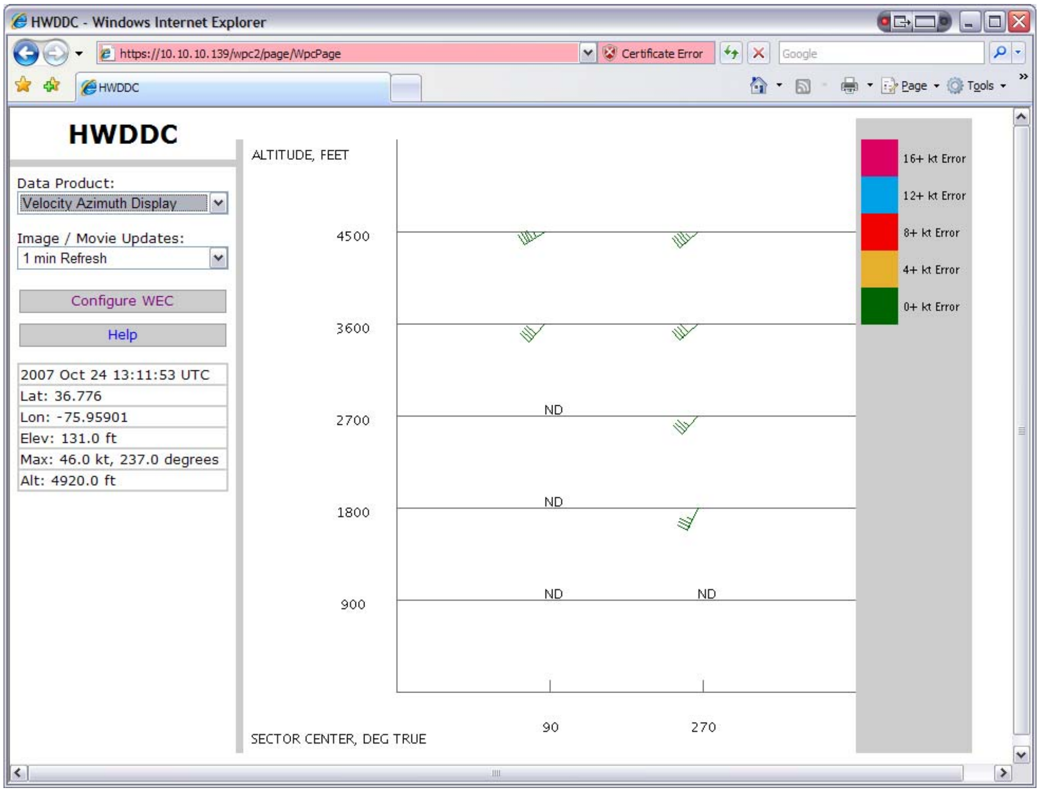
Plot Radius: 50 nmi

Plot Click Action: Show RHI Plot

Data Scale: Knots

Image / Movie Updates: 1 min Refresh

Figure 3: Radial Velocity Display from SPS-48E HWDDC System at Dam Neck, VA



Data Product: Velocity Azimuth Display

Image / Movie Updates: 1 min Refresh

2007 Oct 24 13:11:53 UTC
Lat: 36.776
Lon: -75.95901
Elev: 131.0 ft
Max: 46.0 kt, 237.0 degrees
Alt: 4920.0 ft

Figure 4: Velocity Azimuth Display Vertical Wind Profile from SPS-48E HWDDC System at Dam Neck, VA

3. ACKNOWLEDGEMENTS

The HWDDC and TEP efforts could not have been completed without the dedication and sponsorship of the Program Executive Office – C4I and Space (PMW-120). The authors thank Mr. Thomas Piwowar, and CAPT Mike Huff for sponsoring the HWDDC version 0 and version 1 efforts and the SPY-1 Tactical Environmental Processor effort, as well as the captains and crews of the USS PELELIU and USS GEORGE WASHINGTON.

4. REFERENCES

Maese, T., J. Melody, S. Katz, M. Olster, W. Sabin, A. Freedman, and H. Owen, 2001: Dual-use Shipborne Phased Array Radar Technology and Tactical Environmental Sensing, *Proceedings of the 2001 IEEE Radar Conference*.

B. C. Armstrong, 1992: A Comparison of Conventional, Adaptive and Hybrid Doppler Processing Techniques, *Proceedings of the 1992 South African Symposium on Communications and Signal Processing*, pp. 127-134.